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A Summary of Current Program 7/1/67
and Preliminary Report of Progress
for 7/1/66 to 6/30/67

FOREST SERVICE

of the

UNITED STATES DEPARTMENT OF AGRICULTURE

and related work of the

STATE AGRICULTURAL EXPERIMENT STATIONS

This progress report is primarily a tool for use of scientists and administrators in program coordination, development and evaluation; and for use of advisory committees in program review and development of recommendations for future research programs.

The summaries of progress on USDA and cooperative research include some tentative results that have not been tested sufficiently to justify general release. Such findings, when adequately confirmed, will be released promptly through established channels. Because of this, the report is not intended for publication and should not be referred to in literature citations. Copies are distributed only to members of Department staff, advisory committee members and others having a special interest in the development of public agricultural research programs.

This report also includes a list of publications reporting results of USDA and cooperative research issued between July 1, 1966, and June 30, 1967. This progress report was compiled in the Forest Service, U. S. Department of Agriculture, Washington, D.C.

UNITED STATES DEPARTMENT OF AGRICULTURE

Washington, D.C.

July 1, 1967

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ROCKY MOUNTAIN STATION

TABLE OF CONTENTS

		Page
I.	TIMBER MANAGEMENT RESEARCH	1
A.	SILVICULTURE	1
	1. Site Evaluation and Soil Improvement	2
	2. Artificial Regeneration	5
	3. Natural Regeneration	9
	4. Multiple-use Silviculture	13
	5. Stand Improvement	14
	6. Animal Damage	15
	7. Growth Requirements	17
B.	TIMBER MEASUREMENT AND MANAGEMENT PLANNING	27
	1. Growth and Yield of Forest Trees and Stands	28
	2. Forest Measurement	31
	3. Management Planning Procedures	32
C.	FOREST GENETICS	36
	1. Inherent Variation	37
	2. Hybridization	41
	3. Methods Used in Tree Breeding	42
D.	TIMBER-RELATED CROPS	48
	1. Naval Stores	50
	2. Maple Sap Production	50
	3. Shelterbelts	51
	4. Other	52
II.	WATERSHED, RECREATION, AND RANGE RESEARCH	55
A.	FOREST SOIL AND WATER RESEARCH	55
	1. Water Yield Improvement	56
	2. Prevention of Watershed Damage	61
	3. Rehabilitation of Damaged Watersheds	66
	4. Soil Improvement	70

		Page
B.	FOREST RECREATION RESEARCH	78
	1. Income Opportunities and Economic Impacts of Forest Recreation	79
	2. Forest Recreation Use and Its Physical Impacts Upon the Forest Environment	82
	3. Design and Enhancement of Forested Landscapes	83
C.	RANGE MANAGEMENT	86
	1. Characteristics and Requirements of Range Plants	87
	2. Range Vegetation Evaluation	91
	3. Livestock Grazing Practices	94
	4. Burning and Other Range Improvement Practices	98
	5. Range Pest Influence and Control	101
D.	WILDLIFE HABITAT MANAGEMENT	107
	1. Wildlife Habitat Improvement	108
	2. Integration of Wildlife, Livestock, and Timber Production	112
	3. Evaluation of Wildlife Habitat	113
III.	FOREST PROTECTION RESEARCH	124
A.	FOREST FIRE	124
	1. Fire Physics and Chemistry	126
	2. Atmospheric Physics and Forest Fire Meteorology	127
	3. Fuels and Fire Behavior	129
	4. Fire Prevention and Use of Fire	130
	5. Fire Control Methods and Systems	133
B.	FOREST INSECTS	139
	1. Biological Control	140
	2. Chemical Control	143
	3. Other Control Methods - Male Sterilization, Tree Resistance, Site and Stand Manipulation, Attractants	145
	4. Biology and Ecology	147
	5. Insect Physiology	155
	6. Insect Rearing Methods	156
	7. Survey and Sampling Techniques	157

		Page
C.	FOREST DISEASES	167
	1. Seed and Seedling Diseases	169
	2. Root Diseases	171
	3. Stem Diseases	176
	4. Foliage Diseases	186
	5. Systemic Diseases	189
	6. Decay of Wood and Wood Products	189
	7. Miscellaneous Disease Studies	193
IV.	FOREST PRODUCTS AND ENGINEERING RESEARCH	203
A.	FOREST PRODUCTS UTILIZATION RESEARCH	203
	1. Wood Structure and Quality Relations	204
	2. Solid Wood Processes and Products Development	206
	3. Pulp and Paper Products and Processes Development	209
	4. Chemistry of Wood	210
	5. Serviceability of Wood Products in Use	212
	6. Wood Strength and Structural Concepts	213
	7. P. L. 480 Research	216
B.	FOREST ENGINEERING RESEARCH	224
	1. Systems for Steep Erosible Mountain Slopes (Rocky Mountain)	227
	2. Systems for Deteriorated Northern Hardwoods	227
	3. Harvesting Systems for Difficult Access	227
V.	FOREST ECONOMICS AND MARKETING RESEARCH	229
A.	FOREST SURVEY	229
	1. Field Inventories	230
	2. A Third Look at the Timber Resources in North Carolina and Minnesota	230
	3. Photographic Techniques for Estimating Insect Damage in Western Forests Reduces Survey Cost	230
	4. First Comprehensive Surveys of Timber Resources in New Mexico and Arizona Completed	231
	5. Pulpwood Production in the Northeast	231
	6. A System for Processing Forest Inventory Data	231
	7. Photo Identification Guide for Land and Forest Types in Interior Alaska	231

		Page
B.	FOREST ECONOMICS	234
	1. Economic Guides for Blister Rust Control in the East.	234
	2. A Computer Program for Evaluating Long-term Forestry Investments	235
	3. Economic Returns from Private Woodlands in Indiana	235
	4. A Computer Program for Calculating Allowable Cut Using the Area-volume Check Method	235
	5. Logging Road Standards	235
	6. Increasing Shortages of Black Walnut Veneer Timber	235
	7. Woodland Owners in West Virginia	236
C.	FOREST PRODUCTS MARKETING	239
	1. Rising Trends in the Demand for and Prices of Most Timber Products	240
	2. The Market for Southern Pine Studs in Georgia House Construction	240
	3. Hardwood Lumber Preferences of Three Major User Groups	240
	4. Proper Air-drying Practices can Increase Profits of Lumber Producers and Reduce Remanufacturing Costs of Lumber Users	241
	5. The Manufactured Home--An Important Market for Wood Products	241
	6. Hardwood Sawmills Can Increase Profits by Sawing Dimension Lumber and Timbers	242
	7. Applying Linear Programming in Forest Industry	242
	8. Price Comparisons for Pine Veneer Bolts, Saw Logs, and Pulpwood	242
	9. Minnesota's Aspen Supply--Present and Future	242
	10. Log Exports Continue to Rise in Pacific Northwest	243
	11. The Market for Wood Pallets in the Steel Industry	243
	12. Pulpwood Chip Production and Markets in the Lake States	243
	13. Costs and Returns for Hardwood Lumber Production	243
	14. Determining Weight-volume Relationships for Saw Logs.	244
VI.	PROJECT CHECK LIST	247
	TIMBER MANAGEMENT RESEARCH	247
	WATERSHED, RECREATION AND RANGE RESEARCH	254
	FOREST PROTECTION RESEARCH	259
	FOREST PRODUCTS AND ENGINEERING RESEARCH	271
	FOREST ECONOMICS AND MARKETING RESEARCH	275

INTRODUCTION

This report summarizes progress during the past year in the forestry research program of the Department of Agriculture. Included is research carried on directly by Department scientists and that done cooperatively with other agencies. A summary of new information for each subject-matter area is followed by a list of pertinent publications. The report concludes with a tabulation of currently active research projects.

Included in the summary for each subject-matter area is a statement of the total number of scientist man-years of research at the State Agricultural Experiment Stations and additional State institutions which have forestry schools participating in the McIntire-Stennis Program--60 institutions in all. The figure reported for each problem area is a total of current effort under Hatch, McIntire-Stennis, and non-Federal (State) funding. The national total for all problem areas at State Agricultural Experiment Stations and forestry schools is 466 scientist man-years. Research progress under the McIntire-Stennis Program is described in some detail in a national report issued early in the spring of each year.

A scientist man-year is the equivalent of one year's time of a research scientist who is professionally trained and has responsibility for planning and doing research.

The Department's research program contributes to the fund of knowledge on which depends effective management of all the Nation's forest lands for timber, watershed, recreation, wildlife habitat, and range benefits. Specifically, the research program provides the basis for management of the National Forests and National Grasslands by the Forest Service. It furnishes the technical base for protecting, developing, and utilizing the resources of forest and range lands administered by other Federal agencies. This research program provides much of the scientific and technical guidance for the forest-dependent industries and for the resource management and development programs of the States. And, it contributes toward the more efficient and effective utilization of forest products.

The National Forestry Research Advisory Committee annually reviews the forestry research of the Department of Agriculture. Progress during the past year and plans for the year ahead are discussed. The aim is to concentrate available resources on the more pressing problems and at the same time maintain proper balance toward achieving long-range objectives. Coordination of research efforts receives attention.

The Department's forestry research program is also guided by A National Program of Research for Forestry. This report was prepared by a Forestry Task Force for the Agricultural Research Planning Committee of the U. S. Department of Agriculture and the State Universities and Land Grant Colleges. This planned research program for forestry is within the framework of A National Program of Research for Agriculture. Research to be undertaken through USDA and the educational institutions making up the Association of State College and University Forestry Research Organizations (ASCUFRO) is included. This provides for a highly coordinated and thoroughly planned program of research that is directed at solving, through joint efforts, the most pressing forestry problems.

Research undertaken directly by Department scientists is conducted at the national headquarters, Washington, D.C., at the Forest Products Laboratory, Madison, Wisconsin, and eight Regional Forest Experiment Stations which carry out projects at a number of locations throughout the United States; and at the Institute of Tropical Forestry in Puerto Rico. Most of the research is headquartered on or near the campuses of colleges and universities. There are 341 active projects requiring about 916 scientist man-years of professional effort.

Department research effort extends from the initial development of information to its application. Examples from the past year follow:

A fast way to grow sycamore fiber has been developed. A new concept in the production of pulpwood has been devised cooperatively with the School of Forestry of the University of Georgia and the Georgia Forest Research Council. Short-term rotations of closely spaced sycamore show promise of yields several times that produced by conventional methods. Yields as high as 113 tons per acre in five years have been obtained from sycamores planted at 4x4-foot spacing. Harvesting with highly mechanized machinery and then pulping the small stems and leaves offers an inexpensive and rapid way to produce and use sycamore fiber.

A quick way to attach wood panels to walls. A fast, economical, new method of attaching plywood paneling to existing interior walls has been developed. The panel system, called "Fur-Lok," was recently installed at an on-site demonstration in a New York tenement building scheduled for renovation. Using the system for the first time, two carpenters paneled an 8- by 17-foot room, including framing around two doors and three windows, in three hours and 23 minutes. Speed of installation is of primary importance for products used in a recently developed 48-hour method of apartment rehabilitation. The Fur-Lok system fits in well with the concept of "instant rehabilitation" that displaces the occupants for a minimum of time. It can be used for much of the 2.3 billion square feet of new walls required in New York City alone. And the system can play a part in providing inexpensive but decent housing for many families.

The sea breeze front along the Pacific Coast may adversely affect fire behavior. Research at the Forest Fire Laboratory, Riverside, California, has found that the sea breeze front along the Pacific Coast may cause unexpected changes in fire behavior. During periods when the marine air layer is shallow and is subjected to intensive daytime heating, a zone of strong temperature gradient remains near the coast while the front continues to move inland. Without the cooling effect typical of sea breeze fronts with deep marine air layers, these shallow marine layers may cause a rapid change in wind direction and in speed without a cooling effect. Fire control personnel should be aware of this effect because unexpected and rapid changes can occur in the behavior of a Pacific Coast fire as a result. A recent research publication provides information on this subject.

Diseased trees can be hazardous. More than two injuries per year, some causing death, have occurred on federally administrated recreation sites in California as a result of falling trees or tree branches. Defective over-mature lodgepole pine trees are among the most serious hazards. One-third of all over-mature trees examined had butt rot; one-half of these decayed trees were rated potentially dangerous. Of trees with fire scars, two-thirds were decayed and one-half of these were hazardous. Research is providing guides for recreation managers to reliably evaluate the hazards of over-mature timber that is exempt from commercial cutting on recreation areas.

Straight studs from southern pine cordwood. Research has developed a process for converting four-foot southern pine cordwood into eight-foot 2 by 4's of Southern Pine Inspection Bureau "Stud" grade or better. The process features finger-jointed and glued four-foot sections from which all drying distortion has been removed. The studs are lighter, straighter, and more easily nailed than the denser southern pine studs to which the trade is accustomed. A single plant could have an annual profit before taxes of $660,000 from 174,000 cords of boltwood. A plant producing 56 million board feet of studs would also produce about 50,000 tons of pulp chips and 65,000 tons of dry shavings.

Intensified management offers better forage and yields better animals. A combination system of grazing seeded and native pine-bunchgrass range provided a two months longer period of high level crude protein and phosphorous than grazing native range alone. These results in Colorado were determined by analyses of forage taken from the rumen of fistulated animals. Due to the longer high-nutrient level, weights of calves at weaning averaged 32 pounds greater and cow grades were higher. The higher cow grades indicate a long-term increase ahead in numbers of calves produced.

Termite insecticides placed in the soil are not hazards to water supplies. There has been some concern over placing chlorinated hydrocarbon insecticides in soils for prevention of termite attacks because of the possibility of contaminating wells and streams. Water emulsions of the insecticides when applied to the soil surface at the rate of 1 percent, penetrated seven different soil types only 4-3/4 inches below the surface. Furthermore, neither bioassays nor chemical analyses have shown any insecticide present in a spring and a swamp downgrade from large termite control plots established in southern Mississippi in 1956 and 1958. These two studies indicate that there has been no significant insecticide movement through the soils studied. Hence, there appears to be no danger of contamination of nearby wells and streams either immediately following or 10 years after soil treatment for termite control.

Southern tree improvement gains exceed expectations. Tree breeding studies in Georgia have shown that substantial improvement can be made in the growth rate and disease resistance of slash pine, the most commonly planted tree in the United States. The seven best progeny groups from controlled breeding produced 80 percent more volume per tree than unimproved trees at 8 years of age. The improved trees will provide an earlier harvest of products and a higher yield per acre.

Business is good in the Western Ski Market--and good for rural communities. Skiers in the Western United States spent $115 million for their skiing in 1964, and jobs in restaurants, motels, ski slopes, and other services were provided to many people during the normally slack non-vacation months. And the market is booming. Skiing in the 12 Western States has tripled since 1955, and is expected to triple again by 1976. This research has provided potential investors a clear picture of the present skier market and a good estimate of its development potential.

Timber and wildlife too! Clearcuts in the southern Appalachian Mountains provided more than 900 pounds of deer browse per acre and over 6000 seedlings of valuable timber species. Deer preferred sprouts to tree seedlings on clearcuts ranging from 20 to 55 acres. Three years after timber cutting, tree seedlings were almost four times as numerous as sprouts yet received only one-fourth the use by deer. Even-aged silviculture also benefits the hunters in that game attracted to the areas are more easily harvested.

Sanitary tissue and toweling from Appalachian woods. High quality facial tissue, toilet tissue, and toweling can be made from a mixture of Appalachian hardwoods and softwoods. The pulp for these papers was produced by using low yield kraft pulping digestions for a mixture of 80 percent hardwoods and 20 percent softwoods. These experiments provide basic knowledge for locating prospective mills close to markets and where there are large quantities of Appalachian hardwoods not now being utilized. A single 500-ton sanitary papermill using this process would utilize about 500 cords of Appalachian hardwood per day, provide employment for about 1000 people, and make products valued at $100,000 per day.

The Texas leaf-cutting ant is controlled in pine plantations. This ant is a serious destructive pest in the upland forests of east Texas and west central Louisiana. Regeneration of pine is impossible in some cases without thorough control of the colonies for several years. A bait containing Mirex, a slow-acting stomach poison, will stop foraging activity of the leaf-cutting ant within five days and destroy the colony within 30 days. Mirex is a surer method of control than fumigation, and it can be applied year long, is safer, and cheaper than fumigation chemicals.

Streamflow is reduced when native hardwood is replaced by pine. At Coweeta Hydrologic Laboratory in the Appalachian Mountains, a white pine plantation used more water than the hardwood forest it replaced. In 1957, when all hardwood trees and shrubs on a 40-acre watershed were cut, water yield increased about 6 inches. But now, with a 10-year-old pine plantation cover on the watershed, streamflow is 3 inches less than the yield predicted if hardwoods had remained. The disparity will probably increase since the young plantation has a basal area of only 30 square feet per acre compared with 85 for the original hardwood stand. In areas where water supplies are critical, conversion of hardwood to pine cover for improving timber values would not appear economically sound from the standpoint of water values.

Machine-driving of wood highway guardrail posts. In cooperation with a guardrail subcontractor and equipment manufacturer, Forest Service research developed a mobile post driver that can drive wood posts as readily as posts of competing materials. Now wooden posts can be installed at rates competitive with posts of other materials, and at less cost. Savings of $1 and $2 over the cost of handsetting wood and $1 to $3.25 over posts of competing materials were demonstrated. Installation rates of 28 to 30 posts per hour can be expected on average sites. Wood is an excellent guardrail post material with strength, cost and service-life advantages over other materials. These findings can result in added outlets for wood posts and safer guardrails for motorists at a cost competitive with other materials.

European red alder improves soil. A PL-480 project in Finland found an increase of nitrogen and pH in soil of European red alder stands, and showed that nitrogen content of conifer needles was greater in alder-conifer stands than in pure conifer stands. In the U.S. this alder is being experimentally tested in mixed plantings with black walnut as a possible way to increase the amount of nitrogen for walnut trees. Results from this PL-480 project have provided important information for American and Finnish forestry.

New range statistical reference now available. A comprehensive and annotated publication entitled "An abstract bibliography of statistical methods in grassland research," has just been issued as U.S.D.A. Miscellaneous Publication 1030 for use by range scientists, educators, and administrators. The 1,118 references are divided into three parts--plant measurement, animal measurement, and statistical theory and method. To increase its utility the references are cross indexed and an author index is given. Requests for the publication are worldwide.

A new saw blade reduces waste. Forest Service research has developed a saw blade that makes less waste than current conventional saw blades. Traditionally, saws have always had a rather wide cutting path and efforts to develop thinner kerfs have not been highly successful even though a substantial savings in volume of sawdust can be realized for each 1/32-inch decrease in saw kerf. The Forest Service Taper-Tension Saw on which letters of Public Patent were grated encompasses a 30-percent narrower saw kerf than is commonly used in the industry, and has a high degree of sawing accuracy over a wide operational range. The adoption of this saw by the sawmilling industry could result in an annual increase in recovery of solid lumber products valued in excess of $40 million and thereby help close the timber gap anticipated in the year 2000.

Periodic thinnings may be the key to reducing bark beetle damage to second-growth ponderosa pines. Studies of mountain pine beetle outbreaks in young ponderosa pine stands in the northwest have shown that overstocking is a commonly associated stand condition. The first significant infestation generally occurs when stands become overstocked at about 55 to 65 years old. Without thinnings, subsequent infestations are likely to recur at intervals of about 20 to 40 years. These findings suggest that periodic thinnings to maintain low stand densities may prevent conditions favorable to bark beetle epidemics.

Bidrin is effective against cone insects in the Southeast. The systemic insecticide Bedrin when injected into slash pine trees in early May has reduced attacks by Dioryctria coneworms and the slash pine seedworm by 93 and 99 percent. This approach shows great promise for reducing the cost of protecting the valuable pine seed in seed production areas. The seed can be protected on slash pine trees up to 80-feet tall.

Timber industries can use linear programming for assistance in selecting logs best suited for particular products. Firms in the timber industries buy logs that vary widely in species, size, and quality and use these logs to produce products that show even a broader range in size, grade, and intended use. Managers are constantly faced with selecting the kinds of logs that can be most economically used for particular products. A new report explains three situations in which linear programming can be used to help mill managers save money. One of these examples is expanded to serve as a model for prospective users.

The demand for and the prices of most timber products are showing rising trends. Consumption of industrial timber products in recent years has been substantially above the projections contained in the recent Forest Service report "Timber Trends in the United States." This was caused by a rate of economic growth that has been materially in excess of the projections available at the time the Timber Trends study was made in 1963 and 1964. Studies have also revealed rising trends in the prices of stumpage, logs, and most timber products and growing imports of veneer, plywood, wood pulp, and newsprint.

New research progress with white pine blister rust now opens the door for critical studies of rust resistance. Until recently researchers could not consistently innoculate experimental white pines with blister rust. Now conditions essential for infection of eastern white pine needles by the rust Cronartium ribicola have been found through cooperative research at the University of Wisconsin. To make successful innoculations, it is necessary to control the diurnal temperature fluctuation from 40 to 75°F. At these fluctuating temperatures, the germ tubes penetrate the stomatal openings in the needles and give rise to infection hyphae. This newly acquired ability to successfully infect needles now opens the door to critical studies of rust resistance and resistance mechanisms.

Simulating the rise and fall of forest insect outbreaks with computers can help to control insects. In the Lake States a computer program has been developed for simulating insect survival and abundance over any number of generations. Different patterns and intensities of survival can be specified to simulate--how the numbers of insect pests fluctuate through time. This program provides a means of rapidly exploring with computers the probable effects of control methods before they are used.

Considerable expense and effort can be conserved by knowing the degree of long-term control that is needed and by identifying the best time in a particular life cycle for applying control measures.

Returns on investments in woodlands average 4-1/2 percent in Indiana. On 50 small non-industrial holdings in Indiana the average annual net return per acre of woodland was about $7. This is a relatively high rate of return because of the small investment needed. Investments in land and timber ranged from a low of $34 per acre to $660 per acre, averaging about $170 per acre. The rate of return from timber management was about 6 percent on some properties and averaged about 4-1/2 percent on the 50 woodlands studied.

Extending the use of prescribed fire into the winter can increase the browse for livestock and wildlife. Prescribed fire is effective for increasing the food supply for stock and wildlife in the Southwest. When the tops of valuable browse species are burned, a dense sprout growth is produced. Those succulent sprouts are more accessible and also more nutritious and palatable than the larger woody growth. However, the short season for burning brush has limited the use of prescribed fire. Scientists in Arizona have now found that a 2, 4, 5-T diesel oil treatment applied to scrub live oak in January kills the brush so that it can be burned in wintertime. This practice has greatly increased the acreage that can be treated each season, and thus has increased the supply of browse for livestock and wildlife.

Improved photographic techniques are reducing the costs of surveys of insect damage. The cost of surveys of insect damage in western forests can be reduced by 25 to 50 percent. The step-by-step directions for conducting surveys with this more efficient technique were published recently and are now readily available.

I. TIMBER MANAGEMENT RESEARCH

A. SILVICULTURE

Problem

The broad field of silviculture includes the problems of growing and tending forest trees and stands from seed to sawtimber. It deals with reproducing forests both naturally and artificially, with intensive cultural measures for increasing the yield and improving the forest stands, with methods for evaluating and improving the productive capacity of forest soils, and with stand treatments required to perpetuate valuable species adapted to the site. Related to all of these problems are the basic physiological processes involved in tree growth.

Evaluation of soils and sites for the establishment, growth, and development of various tree species is basic to forest management. Knowledge of proper species or mixtures best adapted to particular sites is needed to guide regeneration programs, timber stand improvement operations, and stand conversion. Growth rates in response to cultural measures are the basis for investment decisions. The integration of fundamental and developmental research into systems for managing forest properties is the final phase of silvicultural research. Forest managers need to know how various prescriptions for better forest practices fit together into a unified management program. They also need to know how best to modify the silvicultural practices to accommodate other forest uses such as watershed, range, and wildlife management and recreation on areas managed for timber production.

USDA and Cooperative Programs

A continuing program of silvicultural research is conducted at all eight Forest Experiment Stations and the Institute of Tropical Forestry in cooperation with various schools, State forestry groups, private industries, and other private forest landowners. Included is a comprehensive program of basic and applied research in seed production and seed handling, forest nursery practice, site preparation, direct seeding, and planting techniques for important timber species. Also included at specialized laboratories are studies on the uptake of systemic chemicals, the physiology of wood formation, the control of growth and dormancy, role of mycorrhizae, mineral nutrition of trees, breakdown of litter into humus, physiological control of flowering and fruiting, and growth in relation to soil characteristics. Studies of natural regeneration and of the care and improvement

of existing forests through pruning, thinning, weeding, and other stand improvement measures are carried on in all Experiment Stations.

A long-term program of research comparing different silvicultural systems in different forest types and stand conditions is conducted at many of the Stations to provide operational answers for forest managers. Such studies often are conducted in cooperation with timber companies who may provide forest lands or purchase timber under contracts requiring species treatments and records. Research is being conducted under Forest Service grants at the University of Georgia on uptake and translocation of pesticides by woody plants; at the University of Florida on the biosynthesis of cellulose in trees; at the University of California on the palatability of tree species; at Washington State University for the development of an ecological classification system in Northern Rocky Mountains, and at New York State University at Syracuse on the biochemistry of seed dormancy. A pioneering research unit at Rhinelander, Wisconsin, is studying the physiology of wood formation of trees and another pioneering unit at Research Triangle, North Carolina, is conducting research on the role of litter in forest soils. The total Federal effort in silvicultural research in the United States amounts to about 143 man-years annually.

A program of research is also carried on under Public Law 480 in Chile, Colombia, Israel, Poland, India, and Brazil.

Program of State Experiment Stations and Schools of Forestry

A total of 49.8 scientist man-years is devoted to this area of research.

Progress -- USDA and Cooperative Programs

1. Site evaluation and soil improvement

Trees respond differently to variations in soil and other environmental factors. The success of silvicultural practices depends to a substantial degree on understanding and clear definition of those factors.

For the uplands of western Iowa a guide has been developed for selection of tree species suitable for windbreak and forest plantings. Eleven of twenty-four coniferous species planted in 1949 are adaptable to local conditions. Degree of success for most of the promising species was correlated with depth to free carbonates in the soil. On the more adverse sites best performers were eastern redcedar, Scotch pine, Australian pine, and ponderosa pine. On the better sites, European larch, white pine, red pine, and northern white-cedar grew well.

Site index for sweetgum in the Coastal Plain of Delaware and Maryland was determined to vary from 68 to 96 at age 50. Soil factors accounting for half of the observed variation were: Alluvial or residual origin; the content of fine sand, clay, and silt in the B horizon; and the depth to a tight horizon. Best sites were alluvial soils and poorest were muck soils.

The selection of best species for a site also requires consideration of its susceptibility to damaging agents. In the sandhills of northwest Florida, shortleaf, loblolly, and Choctawhatchee sand pine are attacked by tip moths. A study to determine the degree of severity of tip-moth damage between pines disclosed that all three species were heavily infested, but only loblolly pine incurred severe growth losses. Height growth of loblolly was reduced about four feet during the 5-year observation period. It was concluded that the high cost of controlling tip-moth damage excludes loblolly as a candidate species for the sandhills area. Choctawhatchee sand pine is recommended because of its resistance to tip-moth damage and its adaptability to the drought, infertile sandhill soils.

Nutrient availability and leaching of cations are influenced by cation-exchange characteristics of the soil material. Some characteristics of the cation-exchange complex of forest floor materials were investigated in the North Carolina Piedmont. Regardless of the tree species and state of decomposition, cation-exchange capacity was highly correlated with nitrogen content of the forest floor material. In many sandy soils the cation-exchange capacity of the forest floor is greater, quantitatively, than that of mineral soil; therefore, the influence of forest floor materials must be taken into account when evaluating properties of forest soils.

In Finland, a PL-480 project had the objective of determining the effect of silvicultural practices on various forest floor fauna. In general, results show that burning, thinning, and the use of insecticides bring about a reduction in the populations of Arthropods, Annelids, and Nematodes. The practices of clear-cutting, fertilizing, and reforestation produced increases in some animal groups and decreases in others. This fundamental knowledge of the role of animal life in soil development provides a firm basis for further research toward effective soil management practices.

An exploratory study under true fir-hemlock stands in the Cascade Mountains of Oregon and Washington determined that forest floor nutrient content varied little between ecological provinces along a 300-mile, north-south transect. Exceptions were higher phosphorus under Pacific silver

fir stands, and more exchangeable calcium under noble fir stands. The forest floor contained about one-fourth of the total available nutrient supply in the organic layer-mineral soil complex.

Occasionally some apprehension arises about the possible deleterious effects of prescribed burning on site productivity when burning is used to control plant competition, reduce fire and disease hazard, and improve game habitat. A study showed that five biennial burns on one area and nine annual burns on another did not adversely affect soil chemical and physical properties in southern pine flatwoods. However, a trend was found in the 0- to 2-inch layer toward a reduction in organic content, in large-pore volume, and in nitrogen content. This slight degradation may be negligible in practice where several years elapse between burns.

Prescribed burning in a shortleaf pine stand in the Ouachita Mountains of Arkansas partially reduced aggregation in the surface soil, lowered porosity, and increased bulk density. However, all of these soil properties had restabilized at pre-burn levels within 4 years after the fire. Neither moisture-holding capacity nor texture was changed significantly by the fire.

Soil moisture observations in upper Michigan showed how the depth of permeable surface soils affects the movement of gravitational water in the soil. A neutron soil moisture probe detected and traced the lateral movement of subsurface storm-flow. Percolation virtually ceased where the subsoil (B1 horizon) began, and where macropores were few. Here moisture became suspended and flowed laterally. This information helped explain the occurrence of dry land vegetation on ridgetops and upper slopes.

In addition to being a reservoir of moisture for plants, soil provides most of the other elements required in growth, but not always in optimum quantities. An increasing flow of information is showing the conditions under which tree growth can be accelerated by addition of fertilizer, particularly nitrogen. In Oregon ammonium nitrate and treble superphosphate were applied to irrigated 7-year-old ponderosa pine in a factorial design at 0, 100, 200 lb/acre rates and repeated at age 9 years. Nitrogen stimulated tree growth in relation to amount applied. Nitrogen plus phosphorus in various combinations stimulated or decreased growth. In Minnesota peat bogs, nitrogen and phosphorus fertilizers were applied to a black spruce stand. Growth was increased by either element, but best growth was produced by combination of the two. In Louisiana on sharkey clay soil both diameter and height growth of 20-year-old sweetgum and red oak were increased significantly by annual application of ammonium nitrate and a complete N-P-K fertilizer. Trees of a loblolly pine plantation in Arkansas

responded to two successive applications of nitrogen fertilizer, but for each treatment the effect on growth lasted one year. In a seed production area in northern Idaho, addition of N and NPK on thinned stands of western white pine caused an additional increase of 36 percent in diameter growth. Lack of response to fertilizer treatments in the unthinned stands was attributed to soil moisture deficiency caused by competition.

A PL 480 project in Finland contributed a considerable amount of new information on nitrogen fixation by non-leguminous plants, and particularly by the silviculturally important alder tree species. In summary, the investigator (1) successfully isolated several strains of Actinomycetes (fungi that decompose organic matter) from root nodules and from soil of alder stands, (2) determined that nitrogen content of alder leaves and litter was 2 to 4 times higher than that of other tree species in Finland, (3) found an increase of nitrogen and pH in soil of alder stands, (4) showed that nitrogen content of conifer needles was greater in alder-conifer stands than in pure conifer stands, (5) measured early growth increases for spruce seedlings following additions of alder litter, and after interplanting with alder seedlings, and (6) discovered an antagonistic effect of several strains of Actinomycetes on the root-rot fungus, Fomes annosus.

2. Artificial regeneration

a. Seed production and handling

The production of tree seed for planting involves a chain of events where insufficient knowledge of any part may nullify the best practices in others. For example, periodicity of seed crops must be known to provide lead information on volume of seed needed on hand to carry through crop failure years. If seed must be held for several years, proper storage technique must be developed to maintain seed viability. One need for determining character of the oncoming seed crop is to learn more about the factors that determine seed set. In southwest Alabama a study showed that isolated pines can pollinate and be pollinated by others over great distances. Pollen dispersal was measured from a longleaf pine isolated from others by at least one-half mile. The high ratio of drift to deposition and the fairly uniform high level of pollen found throughout the sample area suggests that distribution appears to be governed more by air movement than by gravity, and the density of a pollen cloud more a function of diffusion and dilution with distance than of fallout. These results suggest that effective isolation of small longleaf pine seed orchards or seed production areas will be a difficult task in or near extensive longleaf pine forests.

A device to aid in sampling and recording amounts of pollen on a 24-hour-a-day basis was developed at Crossett, Arkansas. The device consists of a vacuum pump air intake of known volume. The intake is vaned for into-the-wind sampling. Pollen is filtered out of the air stream and caught on an adhesive-treated surface of a drum driven by an 8-day clock. This device makes it feasible to establish pollen samples in remote locations where daily trips would be impractical.

Artificial ripening of cones is a possible way of lengthening the cone collection period. Of nine treatments tested in a study of maturity indices for grand fir in northern Idaho, all except one allowed further ripening of immature cones. The best treatment for cones collected 1 month prior to natural maturation, was partial immersion in a nutrient solution. This treatment yielded seed with over 60 percent germinability compared to 30 percent germinability following a normal storage procedure. This germinability compares favorably with approximately 70 percent for seed collected at the time of natural dissemination. The naturally short cone collection period might be lengthened to 4 weeks without appreciable loss of seed quality by adapting these techniques to commercial practices.

Seed of sugar pine, an important western timber species, also react positively to artificial ripening treatments. Cones normally ripen in September and October. Seeds collected after the second week of August were brought to maturity, while those collected before the second week of August could not be ripened. It was found that rate of seed maturation varies from tree to tree, locality to locality, and year to year.

Tons of seed are needed each year for nursery and direct seeding operations. Proper storage conditions must be practiced to insure adequate seed supplies for succeeding seed crop failures. In the southern pine region a 5-year study was made to determine the effects on germinability of length of time, storage temperature, and moisture content of the seed in volume. Germination tests after 5 years showed that longleaf, slash, loblolly, shortleaf, and white pine seed can all be stored at any temperature between -5 and 35° F if seed moisture content is kept at 12 percent or below. Storage at 25°F is recommended except for shortleaf, which can be stored safely at 35°F. The results show that with temperature and moisture kept at proper levels seed can be stored for periods as long as 5 years. Seed of all the species tested can be stored together, which eliminates the expense of separate storage facilities for each species.

Successful natural regeneration of lodgepole pine by block clearcutting depends upon an adequate supply of seed stored in closed cones. A survey

of the serotinous cone habit in stands of lodgepole pine on areas near West Yellowstone, Montana, showed that the stands vary greatly in fruiting habit. The number of serotinous cones per acre was estimated to be 153,000 in an even-aged 88-year-old stand on rolling topography, but only 69,000 in an adjacent uneven-aged stand on an alluvial flat. Of the trees in the even-aged stand, 58 percent bore predominantly (90 percent or more) serotinous cones whereas only 38 percent of the trees in the uneven-aged stand bore predominantly closed cones. Stands that have trees with both serotinous and non-serotinous cone habits in the proportions found in this study provide flexibility to the forester in selection of cutting methods.

In direct seeding, it often becomes necessary to hold stratified, animal-repellent coated seed for a few weeks when bad weather delays operations. Occasionally seed must be stored until the following year. Using procedures developed at Alexandria, Louisiana, repellent-coated southern pine seed may be stored for at least 1 year, even after stratification, without losing viability or becoming dormant, and with no reduction in potency of recommended repellent chemicals. Longleaf, shortleaf, slash, and loblolly pine each require slightly different handling, but in general, seed are either dried to 10-percent moisture before storage or stored moist at 25° F. Restratification of dried seed is unnecessary.

In direct seeding practices, seed are intentionally covered with soil and germination takes place in darkness. Recent research showed that loblolly pine seed would germinate quickly and completely in darkness after stratification for 112 days at 10° C. A temperature of 5° C is recommended, however, to avoid danger of heat accumulation during stratification of large quantities of seed. Application of this information for after-ripening loblolly should substantially improve chances for successful direct seeding operations.

b. Nursery practices, seeding and planting

Nursery practices must be harmonized with seasonal changes in growth and physiological requirements if seedlings of high vigor are to be produced. Through proper timing the benefit from fertilization and root pruning can be maximized and disruption from transplanting and lifting minimized. Study of Douglas-fir seedlings at the U. S. Forest Service's Wind River Nursery shows that a dramatic buildup of food reserves in late fall and winter is followed by an early spring surge of root growth prior to the start of top growth. Root growth becomes slow during the spring period of rapid top growth. Sequence of these events brings out the desirability of lifting seedlings in winter or very early spring to maximize chances for good survival and rapid growth of outplanted seedlings.

High total nitrogen levels in forest nursery soils are usually difficult to maintain because of losses resulting from seedling removal and leaching. An experiment was initiated at the Bessey Nursery in Nebraska to determine the effect of urea-formaldehyde and urea nitrogen on growth of lodgepole pine seedlings when the fertilizers are rototilled into the soil prior to seeding. The study disclosed that (1) liquid nitrogen applied the second season is much more efficient than granular nitrogen added the first season, and that (2) seedling stem diameter can be modified by nitrogen at any given bed density. Soluble urea nitrogen applied as liquid at 50 pounds per acre twice in the second growing season produced significantly larger seedlings than the check, and seedlings equally as large as those given 400 to 560 pounds per acre of granular urea or urea-formaldehyde at seeding time. Applying granular nitrogen fertilizer at seeding time was not advantageous since seedlings did not respond until the second growing season. Much nitrogen was lost through leaching owing to frequent sprinkler irrigation and coarse, sandy soil.

Owners of small tracts have been reluctant to use direct seeding because they lack familiarity with the method. To demonstrate the method and provide a comparison with the better known planting of nursery seedlings, trials were undertaken to determine if direct seeding was as well suited for small as for large tracts. Using slash and loblolly pines, six trials, comparing broadcast sowing, spot sowing, and planting were installed over a 3-year period in Louisiana on sites typical of small tree farmer ownerships. In these studies, broadcast sowing was as successful as planting, while spot sowing was slightly less effective. Costs are about half those for planting. Direct seeding can save tree farmers $6 to $10 per acre in reforestation costs on 50,000 acres annually throughout the South.

Climatic, edaphic, and biotic factors in the Piedmont often create unfavorable conditions for germination and survival of direct seeded loblolly pine. A study showed that sowing of stratified seed from mid-February to mid-March gave best germination and seedling survival, and that stratification was essential for good germination when seed was covered with about one-fourth inch of soil. Tree percentages in late August from stratified and unstratified seed that was broadcast-sown in March were 17 and 1 percent, respectively, resulting in 91 and 12 percent milacre stocking. For seed covered with one-fourth inch of soil, tree percentages in August were 23 percent for stratified seed and 3 percent for unstratified seed.

A study of seeding, planting and site preparation on a 40-year-old brushfield in California disclosed some effective regeneration practices. Brush was satisfactorily controlled by each of several treatments using bulldozer,

brushrake, and herbicide, and combinations of these. Second-year ponderosa pine seedling survival was high -- 90 percent for planting, 88 percent for seed spotting, and 63 percent for drill seeding. Costs for drill seeding and machine planting were about the same, and in both cases about one-sixth the cost of hand seeding and hand planting.

Site preparation in the Hawaiian rain forests was studied to test the effectiveness of herbicide applied by a large turbine mistblower. Almost complete control of woody shrubs was achieved with both Tordon 101 and brushkiller. All rates of these two herbicides were effective. The excellent control of woody shrubs scattered in patches of dense treefern indicates that good spray coverage was achieved with the turbine blower. Control of treefern itself, however, was marginal, but sufficiently encouraging to expect better results with modified treatments.

The possibility of late planting in slash pine has been studied in the summer rainfall climate of northern Florida. Results from four separate studies involving three site treatments on poorly drained and excessively drained soils show summer planting to be acceptable. Survival averaged about 74 percent after planting. Lengthening the planting season provides added flexibility for both the nurserymen and forest managers for coordinating use of manpower and equipment in growing and planting operations.

Most hardwoods withstand flooding in the dormant season, but few tolerate it during the growing season. One-year-old sycamore, sweetgum, and Nuttall oak seedlings potted in Commerce silt and Sharkey clay, typical soils of the Mississippi Delta, withstood up to 16 weeks of soil saturation from the time of planting with no significant effect on survival, but severe reductions in seedling height, root, and stem diameter growth occurred after 10 to 12 weeks. This critical period corresponded to a rapid increase in soil temperatures in mid-April. Saturated Commerce silt loam was more detrimental to seedling growth than was saturated Sharkey clay.

3. Natural regeneration

Observed patterns of seed dispersal of cottonwood in the lower Mississippi have considerable silvicultural significance. Cottonwood flowering occurs over a 1-month period -- from early March to early April -- and seed dispersal lasted from mid-May until late August. This wide variation within stands and predictable tree-to-tree flowering sequences suggests strong genetic control of flowering dates and seed dispersal events. This long dispersal period insures the presence of adequate seed for natural regeneration along receding water courses as new ground is progressively exposed.

Successful coppice regeneration of sycamore is an important element of the high production and short rotation management potentials of this species. This new concept in the production of pulpwood has been developed cooperatively with the School of Forestry of the University of Georgia and the Georgia Forest Research Council. Short-term coppice rotations of closely spaced sycamore with highly mechanized harvesting promises pulpwood yields of fiber several times greater than that produced with present methods. Yields as high as 113 tons per acre in 5 years have been obtained from sycamores planted at a 4 x 4-foot spacing. Closer spacings and shorter rotations are visualized. Pulping tests showed bark to be no problem in unbleached sulfate pulp. Further tests in which entire young sycamore trees (bark, leaves, twigs, and wood) were chipped and cooked together produced paper of excellent quality and suitable for a variety of uses. This species is well adapted to short rotation culture because of its fast growth rate on good sites, good sprouting ability, good response to fertilization and cultural treatments, and its present lack of natural enemies in the South.

Cutting intensity and logging methods can facilitate natural regeneration. In the southern Appalachians large numbers of desirable and undesirable seedlings and seedling sprouts developed after several intensities of logging in mixed oak stands. After 3 years the seedlings and seedling sprouts growing in areas that were clearcut were much taller than those in partially cut or control plots. Regeneration that was on the ground at the time of logging dominated the newer regeneration and will probably make up a major portion of the new stand. The results of this study should give landowners more confidence to use clearcutting regeneration techniques.

Natural reproduction in upland hardwood stands is usually adequate in numbers, and distribution, but the cutting method used influences the composition and development of the new stand. Oaks that survive in the new stand are stump sprouts and new sprouts that came up from advance reproduction present under the old stand. Yellow-poplar reproduction consists of new seedlings that develop from seed stored in the litter. Clearcutting resulted in more new oak sprouts and more and better distributed yellow-poplar reproduction than either selection, shelterwood, or a heavy improvement cutting. The successful use of clearcutting means even-aged management becomes feasible, thus providing more flexibility in land management.

Difficulty in getting paper birch and yellow birch regeneration on clearcuts in the Northeast led to an experiment in which shade was controlled in ways to simulate strip cutting. On an open field, solar screens made of fine mesh

shade cloth were erected in various directions simulating the timber stand edge. Groups of potted seedlings placed at various distances from the "timber edge" were observed for growth and survival as related to shade. Narrow strips (one-half border tree height) oriented either north-south or east-west provided best germination and survival. Growth was not significantly different among treatments. Narrow east-west strips should be desirable where strips can be cut in a progressive series at roughly 3- to 5-year intervals. When progressive strips are not employed, or longer cutting intervals are to be used, wider strips (equal to or greater than border tree height) would appear to be a better choice. These results provide a basis for a practical field trial of strip cutting.

Germination of sweetgum seed was found to be greatly influenced by temperature, moisture stress, and length of stratification. Total germination and rate of germination increased as temperature was raised from 60° - 75° to 85° - 100°F. Increasing moisture stress decreased both total and rate of germination, and 15 atmospheres of stress completely inhibited germination. Increasing temperature decreased the influence of osmotic stress, and lengthening the stratification time diminished both temperature and osmotic effects.

Red alder is the Northwest's leading lardwood and has an important nitrogen-fixing ability. But it also invades conifer sites and interferes with seeding establishment. Although considered intolerant, it survived on plots where solar radiation during the growing season averaged less than 25 percent of radiation in the open. Apparently its characteristic intolerance to shade develops some time after the first growing season. This new information on its early shade tolerance helps form a scientific base for its management or control.

Well-stocked birch stands occupy large burned-over uplands of interior Alaska, while natural forest succession to white spruce occurs only infrequently. An experiment was conducted to evaluate the effect of leaf smothering upon the establishment of white spruce under an 80-year-old, well-stocked birch stand. Hardware cloth screens were used from 1 to 5 years to prevent leaf litter from accumulating on seed spots. Seedling survival increased from 0.6 seedlings per spot with 1 year of protection to a high of 4.9 with 4 years of protection. The average dropped to 4.3 seedling per spot when protected for 5 years. After the fourth season seedlings apparently were large enough to avoid being smothered by fallen leaves. It appears unlikely that more than an occasional white spruce can become established naturally beneath well-stocked birch stands in this region.

Slash burning and prescribed burning have been used in various ways as a silvicultural tool. As an aid to natural regeneration burning must be geared to local conditions, which requires numerous on-the-ground experiments and observation to develop burning prescriptions. In southeast Alaska, the effect of light slash burning after clearcutting of an old-growth western hemlock-Sitka spruce stand was investigated. Seven growing seasons after slash burning, fewer but more evenly distributed seedlings were found in the regenerated stand. Burning also favored Sitka spruce over western hemlock through destruction of advanced regeneration, which was primarily hemlock, and through creating seedbed conditions more favorable for spruce establishment. Slash burning appears to offer possibilities for increasing the percentage of spruce in second-growth stands and for improving spacing.

In Oregon ponderosa pine stands, protection of advance regeneration during harvest of the mature overstory often provides the key to prompt and adequate restocking. A recent pilot-scale logging operation on the Pringle Falls Experimental Forest illustrates how damage to sapling and pole-size trees can be minimized. Practices integrated into the harvesting system included (1) intensive net of narrow, low-standard spur roads, (2) joint selection of landings by operator and forester, (3) limit tractor skidding to two logs per turn, (4) set tongs by groundman rather than tractor driver, and (5) back tractors from landing to logs to avoid turning in woods.

Observations of snow damage to seedlings and saplings in upper-slope forests of the Pacific Northwest showed that leaning, bent, and fractured stems were common after snowmelt. Douglas-fir incurred more damage than true firs, western hemlock, or western white pine, and its greater susceptibility should be considered in selecting species when thinning natural regeneration for upper-slope areas. Trees only moderately damaged often recovered by the third week of the growing season.

Natural regeneration on clearcut tracts in mixed conifer and spruce-fir stands in the Southwest continues to be unpredictable. A survey of 99 cutting units in the Engelmann spruce-subalpine fir forests in Colorado showed that new reproduction and residual understory trees of good quality provided an adequate new stand on all units examined. Disturbed seedbeds with less than 40 percent of the ground covered by slash favor regeneration where a good seed source is available. In the mixed-conifer forests in Arizona, however, only a few seedlings more than 1 year old were found on seven clearcut blocks, 6 years and several moderate to good cone crops after logging. Quite a number of seeds germinated but rodents, the annual May-June drought, herbaceous competition, and frost heaving decimated their numbers. Further research on regeneration of clearcuts in the

mixed-conifer forests rates high priority because these stands are among the most productive in the Southwest.

Regeneration of longleaf pine, a valuable component of southern pine forests, has been a major problem for many years. Prescribed burning to stimulate natural regeneration is appealing to many landowners because of the low cash expenditure. The effects of four site preparation measures on seedling establishment were evaluated. Treatments were: (1) burning, (2) burning followed by strip-harrowing, (3) burning followed by complete harrowing, and (4) burning followed by double harrowing. Seedfall was light and the weather was unfavorable. Seedling establishment on the most intensively treated site - burning and double harrowing - was nine times greater than for the burning-only treatment. These results indicate that with proper seedbed conditions longleaf can be successfully regenerated naturally.

4. Multiple-use silviculture

Allocation of forest land for a variety of uses requires understanding of the factors that give rise to the present condition of the land in question.

In Alaska a unique opportunity occurred to study development of soil and vegetation processes on progressively younger terraces of the McKinley River. Four successional stands and one climax stand in an alpine tundra region indicated five terraces at the following ages: 25 to 30 years, 100 years, 150 to 200 years, 200 to 300 years, and 5,000 to 9,000 years. Vegetation develops from a pioneer stage of low matted shrubs, to a meadow stage, to a shrub stage underlain by a thick moss mat, and finally to a low shrub-sedge tussock tundra. As succession proceeds, silt and clay and humus are added to the developing soil. Nitrogen increases in the upper 10 cm. and the soil reaction changes from a pH of 8.2 to 4.4. In this subarctic environment succession develops from a dry condition on the younger terraces to a moist condition in late successional stages, and finally to a wet tundra in which the underlying permafrost prevents soil drainage. Similar conditions along rivers at lower elevations limit optimum tree growth to the younger terraces where permafrost is lacking.

Recently an immense mass of rock and debris broke loose high on the slopes of Mount Rainier in the Washington Cascades. The resulting series of avalanches swept down Emmons Glacier to deposit an estimated 14 million cubic yards of debris over 2 square miles of the glacier and the sparsely vegetated outwash valley below. Deposits reach thicknesses of about 100 feet in the valley whose original elevation ranged from about 4500 to 5500

feet. Chemical and microbiological properties of the unvegetated avalanche were compared with those of an adjacent 68-year-old morainal soil covered by Alnus sinuata. Soil development is already well underway on the moraine with an accumulation of organic matter, nitrogen, and a lowering of pH. This investigation provided useful data on the rate of forest and soil development in the true fir-hemlock forests of the Northwest and on the nature of landscape changes taking place in areas set aside for recreation and natural beauty.

Oak-hickory forests on the poorer sites in the Upper Mississippi Valley have low productivity and limited esthetic value. An attempt to improve these two characteristics was made by interplanting eastern redcedar in forest openings. Periodic examinations during the following 16 years showed eastern redcedar had performed well. The introduction of redcedar into poor oak-hickory forests increased cover and food for wildlife and improved the beauty of the usually drab forest, particularly in the winter.

5. Stand improvement

Foresters and forest landowners need to know how frequently they should schedule thinnings and salvage operations in Douglas-fir stands. Although light, frequent thinnings are desirable for salvaging dead or dying trees and for removing non-crop trees, the small amount per acre or size of material harvested in such thinnings might result in undesirably high labor costs. An analysis of Douglas-fir production figures from 25 commercial thinning operations over a 14-year span in western Washington showed that tree size influenced labor requirements much more than did the amount of wood removed per acre. Man-hours required for cutting, skidding, loading, and hauling a cord of wood was about the same when as little as 5 cords (400 cu. ft.) or as much as 16 cords (1,300 cu. ft.) per acre were harvested. However, harvesting 18-inch trees required only about 2 man-hours per 100 cubic feet while harvesting 9-inch trees required 4 man-hours. Results indicate (1) the feasibility of scheduling frequent cuttings to remove relatively small volumes of timber per acre and (2) how size of cut trees may influence labor efficiency.

With the increased emphasis on production of high-quality sawlogs, foresters are now more aware of minor stem defects that depress log and lumber quality. Such defects are sometimes caused by epicormic shoots. A study of dormant buds in sugar maple showed that they originate at the terminal bud scar and at the base of lateral shoots. Those formed at the bases of lateral shoots are soon transferred to the main stem and persist for many

years after the shoots die and drop off. A minute annual elongation apparently adds one set of bud scales to a dormant bud. Initially smaller size and the annual elongation distinguishes them from axillary buds. However, they can sprout and produce knots in the stem when conditions are favorable.

Observations made on 350 trees bordering clearcut forest openings in West Virginia indicate that the species studied may be grouped into four classes in order of decreasing susceptibility to epicormic branching. The classes are: (1) white oak, (2) black cherry, red oak, chestnut oak, (3) hickory, yellow-poplar, red maple, sugar maple, and (4) white ash. The results also showed that more sprouts were formed on the second log than on the first and that more epicormic branches developed on the boles of intermediate and overtopped trees than on dominant or codominant trees when exposed by cutting.

A study to upgrade open-grown black cherry on the Allegheny Plateau showed that pruning up to 40 or 50 percent of the total height of such trees was highly beneficial. Trees pruned to 75 percent of their total height had slightly less diameter growth and developed a great many more epicormic branches than trees pruned to either 50 or 25 percent of their height. These results provide a means of salvaging open-grown black cherry trees and developing stands of high potential value. Pruning will likely be needed in the intensive culture of black cherry where wide spacings, as well as fertilization, cultivation, and irrigation, will be used to achieve rapid diameter growth rates.

6. Animal damage

Animal browsing of tree seedlings is considered to be a significant factor influencing the success of reforestation in many areas. Browsing of Douglas fir by black-tailed deer creates such a problem in the Pacific Northwest. In this region it is commonly believed that Douglas-fir is a low-preference species that is browsed only when all other forage is unavailable. However, recent winter season trials indicated that deer ate Douglas-fir seedlings sooner than twigs of other abundantly occurring woody plants including alder, hazel, and vine maple. Choice food was the leaves of blackberry and salal, and twigs of huckleberry and cascara. Results suggested that Douglas-fir browsing might be lessened if its relative preference in comparison with other forage plants could be lowered. Palatability of Douglas-fir nursery seedlings could perhaps be reduced by different nursery practices, or other plants that are more highly preferred by deer might be encouraged.

In central California an experiment was conducted to determine the effect of planting a buffer forage crop to reduce deer damage to ponderosa pine seedlings. A rangeland drill (10 drill openers each spaced 1 foot apart) with compartmented seed hopper sowed ponderosa pine, shrubs, grasses, and legumes in the spring. Plant establishment was satisfactory. Although deer and cattle ate large amounts of seeded plants during the second season, they did not damage ponderosa pine seedlings. Therefore the simultaneous planting of pine, browse, grasses and forbs appears practicable for some areas where conifers must be planted on land grazed by deer.

Adverse effects of browsing are magnified where seedlings are planted on areas where vegetative "competition" is relatively high. To estimate effects of browsing under various degrees of plant cover, Douglas-fir seedlings were planted on four different microsites and clipped to simulate browsing by deer. Survival of seedlings after one field growing season was significantly higher on a sparsely vegetated, recently disturbed site than on areas with greater plant cover. Survival was reduced by heavier clipping. Light to moderate simulated browsing during the winter of planting did not decrease survival after the first growing season. Height growth of unclipped seedlings was poorest on the more shaded site. These results suggest that site preparation will reduce the effects of heavy browsing by deer.

One approach to controlling animal damage to forest trees is through use of systemic chemicals which, when applied to plants, are absorbed, translocated, retained, and recirculated by the plants. Previous research indicated that one chemical, tetramine, might have systemic properties and relative stability in plants. However, our studies with radioactive tetramine showed that the chemical did not possess the desirable systemic properties. The chemical was also absorbed by important browse plants at a much faster rate than by tree seedlings and did not remain in its original form in any of the plant species tested. Tetramine, therefore, is not recommended as a systemic chemical to give tree seedlings "built-in" protection. Application of the chemical to trees associated with browse plants could present a hazard to beneficial wildlife, since tetramine is more toxic than strychnine. As a result of the work on testing tetramine, new analytical techniques were developed that should greatly expedite subsequent experiments with other potential systemics.

A part of research to develop practices to control animal damage is the study of food habits of the animals. In an outdoor enclosure in interior Alaska feeding tests were made with captive red and flying squirrels to determine the quantities of cones utilized. Red squirrels survived on seed from a daily

average of 144 white spruce cones during outdoor winter feeding tests, but they lost weight rapidly on a black spruce seed diet. Flying squirrels apparently do not consume large quantities of white spruce seed. The red squirrels may temporarily move into areas of black spruce during years of low white spruce cone production, but are apparently unable to survive on an exclusive diet of black spruce cones. The study is part of a larger effort to determine the relationships of red squirrels to the production and supply of white spruce seed and the regeneration of white spruce in interior Alaska.

7. Growth requirements

Tree growth is the end result of the interaction of numerous physiological processes, and in order to understand why trees grow differently under various environmental conditions and cultural treatments, it is often necessary to understand how the basic processes which control growth are affected by the environment.

Summer drought is a major factor causing regeneration mortality on clearcuts in the mixed pine-fir forests of southwest Oregon. Using lethal needle-moisture content values it was found that ponderosa pine and incense-cedar were most drought resistant, sugar pine least, and Douglas-fir and grand fir intermediate. These results suggest that ponderosa pine and incense-cedar would be first choice to plant on clearcuts where soil moisture was known to be critical.

Dormancy has been defined as "all instances in which a tissue predisposed to elongate or grow in some manner does not do so." For white spruce it was determined that in order to break dormancy seedlings should be chilled 4 to 8 weeks at 26° to 40°F. depending on their developmental stage and age when the treatment is begun. Young plants apparently require more chilling than older ones. Long photoperiods compensate for lack of chilling. In young plants -- at least to the age of 2 years -- long day conditions also extend the growth period. In plants that have passed through five normal periods of growth, long photoperiods result in greater elongation in previously formed internodes. The results of this research will simplify the management of white spruce in the greenhouse and will be of importance in the planning of future studies of the physiology of white spruce growth.

The survival of planted tree seedlings is strongly dependent on the speed with which new roots develop after planting. A controlled environment study was used to investigate the effect at one such factor -- night temperature -- on ponderosa pine root regeneration. Seedlings were exposed to different numbers of cold nights (6°C) for as long as 6 months in growth chambers.

Exposure to 90 cold nights brought about a significant increase in the number of old roots which elongated following transplanting. An exposure of 120 cold nights brought about a significant increase in the number of new roots initiated following transplanting. These results suggest that a minimum of 90 to 120 cold nights are needed to get the best conditioned seedling for transplanting. Preconditioning seedlings at low temperature to improve their root regeneration ability just prior to transplanting may also be possible.

Intensive soil management practices, cumulative effects of relatively heavy fertilizer applications, and differential leaching all combine to produce a unique nutrient regime in forest tree nurseries. Foliar discolorations and abnormal growth patterns are often due to imbalances of the nutrients in the soil rather than deficiencies per se. A study was made to create abnormal growth patterns and identify their causes. Slash pine seedlings, both in the nurseries and in the greenhouse were treated in a factorial fashion with varying N, P, K, Ca, and Mg levels. Many of the treatments caused abnormalities. Needle discolorations known as "hot weather chlorosis" to nurserymen in Georgia were caused to a large degree by heavy nitrogen applications and residual nitrogen in the soils. Furthermore, the results of the study indicate that heavy applications in the past have raised soil phosphorus to levels adequate for tree seedling growth. Continued doses of phosphorus will cause soil imbalances detrimental to the seedlings.

For a long time germination was considered to be a relatively simple process; seeds were composed of a naturally dried substance which contained the nutrients necessary for initial growth and which only needed rehydration in order to start growing. Scientists working on a PL 480 project in Spain have determined that along with this basic phenomenon a diversity of biochemical activities take place imposed by the surrounding conditions. Species chosen for the investigation were Pinus pinaster and P. pinea. A notable finding was the decreases of storage carbohydrates and the breakdown of protein into fractions of lower molecular weight. Energy supply at the starting point seems to be dependent on the breakdown of the carbohydrates. The carbohydrate reserve apparently activates the preparation mechanisms for germination as soon as moisture and temperature conditions become favorable. Cold serves as a repressor of the seeds already prepared. The outstanding result was the finding that ribonucleic acids increase markedly and quickly during early stages of germination. Knowledge of the biochemistry of seed and germination is fundamental to more effective methods of treating seed to maintain or enhance its quality.

Another PL 480 project in Spain had as its objective to determine the deficiency and toxicity symptoms for the minor elements manganese, molybdenum, and boron on Monterey pine. Manganese and boron were accumulated to a higher concentration in the needles than in the stem or roots. In stem and root tips, in the meristematic structures were altered by boron deficiencies and growth in height and weight were sharply reduced. The effects were less noticeable in the needles. Recognition of nutrient deficiency symptoms permits early remedial measures in nurseries and helps explain plant behavior under natural conditions.

It is often desirable in tree improvement programs to propagate specific trees. Rooting and grafting of branches are the only ways, in conifers, to obtain several individuals with identical genetic constitutions. The rooting of Monterey pine cuttings was studied in detail. A hormone, indolebutyric acid, stimulated root formation. Cuttings collected in the fall and placed in cold storage for a period of 20 to 50 days rooted in high percentages. It was possible to propagate some 520 different trees from the native stands of Monterey pine. With the findings of this study, we can recommend procedures for large-scale vegetative reproduction of Monterey pine and some other conifers.

Indolebutyric acid also improved rooting of cottonwood cuttings. A greenhouse test, designed to develop a method of propagating mature wood, dormant cuttings for use in tree improvement research, showed the effects of tree, sex, collection date, indolebutyric acid, and presence of flower buds on root formation. Untreated stem cuttings collected in early February rooted better than those taken in December, January, or early March. Flowering and foliation preceded rooting in March collections and diminished propagation success. Removal of flower buds increased rooting. Tree-to-tree variation in rooting was highly significant as was the promotive effect of IBA treatment. The overall effect of sex was insignificant. It was concluded that cuttings without flower buds taken in late January and treated with indolebutyric acid would propagate best. Mature trees selected as breeding material may be propagated by this method.

The addition of Captan to indolebutyric acid increased rooting success with loblolly pine cuttings. Cuttings were treated with 10 and 25 percent Captan in mixtures with 0.8 percent indolebutyric acid and subjected to rooting at bench temperatures of 72° and 78°F. The higher concentration and higher temperature produced roots on 40 percent of the cuttings from young trees. If the percentage of cuttings successfully rooted can be increased by another 10 percent, it may be cheaper to propagate loblolly pine by rooting than by grafting.

It is known that some hardwood species are tolerant of prolonged inundation of their site while others are intolerant. A study was made to determine the physiological adaptation that makes this possible. The root respiration rates of yellow-poplar, red maple, weeping willow, and black willow were determined manometrically. The species are listed in order of their increased flooding tolerance. The root respiration rates of red maple and weeping willow did not differ significantly; all other species comparisons were significant. The average oxygen uptake per gram of dry weight for yellow-poplar was 3.78, for red maple 5.14, for weeping willow 5.59, and for black willow it was 6.44 microliters per hour. These results show that the root respiration rates under normal soil-aeration conditions increased as flood tolerance increased. But it is not necessarily a cause and effect relationship.

The chemical components of the wood cell have not been systematically investigated with regard to age-related patterns even though such patterns have been suspected of existing. Such a study involving red pine explores their relationships with age. Microsamples of earlywood and latewood from one mature and two young red pine trees were analyzed for lignin and the five principal wood sugars. Glucose and mannose yields increased rapidly with age, whereas the yields of glactose, xylose, arabinose, and lignin decreased. Beyond the juvenile period (15 to 20 years), the yields of all constituents from latewood were essentially parallel to those of earlywood; the main differences were lower lignin and xylose and higher mannose yields from latewood. Qualitative changes in the composition of compression wood with increasing age were also found. Some, but by no means all, of the chemical differences encountered in this study could be accounted for by changes in cell wall thickness. It was concluded that very definite qualitative changes in wall composition occur with age independent of changes in wall thickness. These changes appear to be inherent and may be typified by the trends expressed in the earlywood. Thus, at any one age, the increase in wall thickness that occurs during the latewood formation is superimposed on a predetermined earlywood matrix. These findings add to our knowledge of how wood is formed in trees, which may ultimately enable us to control wood properties to some degree through culture and treatment.

The supply of high-quality black walnut timber is declining and still the demand increases. We know some ways to increase the growth and improve the quality of walnut. But there are gaps in our knowledge. A workshop on

the culture of black walnut was held in Carbondale, Illinois, last August to bring together the information now available on the growing of walnut, and to stress the high priority research needs to fill the culture gaps. Highlights of research presented at the conference are as follows:

Fast-grown walnut wood is found to be equal or superior in machining qualities to wood from slow-grown trees. This means landowners can use every possible means to increase diameter growth of the stem. The crown should begin immediately above the pruned butt log to provide the large leaf surface which is necessary for fast diameter growth of the high-value butt log. No attempt should be made to produce high-value veneer from the upper stem, yet this relatively low-value wood can be used to extend the supplies of walnut lumber and to profitably make some specialized high-value products.

Successful black walnut plantations have been established either by planting 1-year-old nursery-grown seedlings or by direct seeding of nuts. Direct seeding is easier and cheaper, and seedlings from nuts have normal root systems that have not been damaged by transplanting. This means less root disease and faster growth. But, throughout much of the walnut range, squirrels, chipmunks, mice, and other rodents are so numerous that direct seeding is difficult, so planting seedlings is generally considered the best way to establish walnut plantations.

A cooperative study between the Ohio Agricultural Research and Development Center and the U.S. Forest Service was started in the spring of 1965 to study induced deficiency symptoms in black walnut growing in sand cultures. Deficiency symptoms were produced at low concentrations of nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, iron, manganese, zinc, copper, molybdenum, and boron. A book will be published showing the deficiency symptoms in color supplemented by full text descriptions.

A yield table was prepared for unmanaged walnut stands based on measurements of walnut groves planted years ago in the prairie region. Satisfactory growth occurred only where the black walnut site index was 60 or better. It was determined that growing space requirements for black walnut are greater than those previously recommended.

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B. TIMBER MEASUREMENT AND MANAGEMENT PLANNING

Problem

Intensive management of the commercial forests of the United States requires efficient methods of measurement of the contents of trees and stands, and more reliable predictions of future growth, yield, and quality of forest products. Productivity of forests, both in quality and quantity, varies markedly according to stand density, site quality, tree age, and species composition. Optimum stand conditions for particular management objectives need to be determined for the many combinations of timber types, sites, and conditions found in American forests. Important forest regulation problems involving levels of growing stock, cutting budgets, and rotation lengths must be solved. With better information about the response of forests to various cultural practices, more attention must be given to planning and decision-making problems in order to guide management of large public and private timber holdings.

USDA and Cooperative Programs

A continuing program of studies is conducted at all the Forest Experiment Stations, often in cooperation with industries, other private landowners, State forestry agencies, and forestry schools. Special attention is being given to research in the growth and yield of managed forests and forest plantations. Research is also concerned with mathematical techniques and forestry measurement tools that will permit greater precision and efficiency in practical forest management operations in forest research. A Pioneering Research Unit in Berkeley, California, established in 1961, is studying basic measurement problems. Nationwide, 9 man-years of Federal scientific effort are performed in timber measurement research projects, and several additional years are devoted to related growth and yield studies in silviculture projects.

Program of State Experiment Stations and Schools of Forestry

A total of 20 scientist man-years is devoted to this area of research.

Progress -- USDA and Cooperative Programs

1. Growth and yield of forest trees and stands

Douglas-fir is one of the most extensive and valuable timber types in the country. Important questions, including conversion rates of old growth and thinning practices and rotation ages in second growth, hinge on growth potential in this valuable type. In a study recently completed, refined estimates of total production (gross yields) of Douglas-fir stands under 100 years of age were computed from growth rates determined from a combination of permanent and temporary sample plots. Gross cubic-volume growth rates were found to increase rather sharply with stand density, in contrast to current opinion indicating that growth rates are relatively unaffected by stand density. Furthermore, for stands of average density about 30 percent of gross yields were lost to mortality, indicating substantial opportunity to harvest more timber through commercial thinnings. The study also made contributions to the scientific aspects of growth and yield prediction by its use of temporary plots, and its exploration of the troublesome problem of autocorrelation resulting from repeated measurements on the same plot.

Reliable growth and yield information for managed forests is needed for the vast areas containing ponderosa and lodgepole pine in the interior West to weigh not only timber investment alternatives but other multiple-use opportunities as well. A method has been devised to provide yield tables for lodgepole pine in Colorado and Wyoming and for ponderosa pine in the Black Hills which has application in other western regions. A procedure is given to make stem measurements on well-managed stands, and to convert these measurements into interim yield information. The interim yield schedules will serve until results from permanent sample plot systems become available. Information thus far developed indicates yields for managed stands up to double those in unmanaged stands.

A fundamental problem faced by foresters and timberland owners is understanding the growing space requirements for trees in natural stands. A series of 63 tenth-acre plots in 20-year-old even-aged stands of loblolly pine in southeast Arkansas and northeast Louisiana were thinned to different density levels to determine which level would produce optimum growth. Site indexes ranged from 68 to 98 feet, and density levels from 55 to 130 square feet of basal area per acre. Periodic annual increment between ages 30-35 is strongly related to site quality but less affected by stand density. For example, each 10-foot increase in site quality produced

an average increase of 25 cubic feet per acre per year. Maximum volume growth occurred at about 110 square feet of basal area, only about 15 cubic feet (7-10 percent) higher than at 80 square feet.

Closely related to this study was another in which the growth patterns of individual loblolly pines were observed in relation to stand density and crown class. Throughout five growing seasons, diameter growth of 30-year-old trees on plots thinned to 50, 85, and 125 square feet of basal area per acre was measured at 1- to 2-week intervals. Dominants and codominants comprised 75 percent of all trees and 84 percent of the basal area, yet they produced 92 percent of the basal area increment. Plots with 55 square feet, comprised mostly of dominants and codominants with relatively large crowns, produced 90 percent as much basal area growth as plots with 125 square feet whose dominants and codominants had relatively smaller crowns. On the average, annual basal area growth on all plots was one-half completed by May 31 and two-thirds completed by July 15. In dry years, proportionately more growth occurred by these dates than in wet years. Dominants and codominants grew longer and faster in lightly stocked stands than in heavily stocked stands.

Conflicting with the loblolly pine data is evidence developed out of diameter growth studies of yellow birch, one of the high-value hardwoods of the Northeast. The study, in 70- to 90-year old evenaged northern hardwoods, showed that diameter growth of sample trees bore no significant relationship to crown size, tree diameter, or stand density. Since the granitic podzol soils commonly supporting yellow birch contain low levels of essential nutrient elements, investigations of soil fertility and nutrient requirements of yellow birch are being conducted in an attempt to explain observed differences in diameter growth, and lack of sensitivity to stand density and tree characteristics.

Growth reduction of individual trees due to overcrowding is particularly serious in drier regions of the west. Lodgepole pine is probably more subject to stagnation from overcrowding than any other western conifer. A primary goal of management is, therefore, to concentrate wood production on those relatively few stems that will reach merchantable size and prevent wasting production on those many stems that will die from stand competition before they become merchantable. First 5-year results from a levels-of-growing-stock study in central Oregon show that excellent rates of diameter growth can be attained if trees have ample growing space. The study also demonstrates that growth capacity of the site is redistributed very rapidly over a wide range of thinning intensities. For the first 5 years height growth does not differ significantly between densities.

The size of individual trees that can be produced at various ages is especially important in hardwoods where value and quality is tied so closely to log size. A study of 141 unthinned stands of yellow-poplar provides data on diameter distributions in relation to age, site index, and stand density. For example, the data indicate that a yellow-poplar stand growing on site 120 with 100 trees per acre has 12 veneer size trees at age 50, 28 at age 60, and 42 at age 70. Information of this kind will help landowners set thinning schedules, select rotation ages, and determine the potential of their lands for growing particular products.

Potential productivity of forest lands must be known if the land manager is to earn the greatest return from invested capital. Commonly, productivity ratings are obtained from the relationship of tree height to age. Lodgepole pine, however, grows in such dense stands that height growth is reduced. Thus a third variable, stand density, must be considered when site index for lodgepole pine is determined from height-age curves. In a study conducted jointly by the Rocky Mountain, Pacific Northwest, and Intermountain Stations, height-age relationships of dominant trees with correction for stand density were developed for lodgepole pine. Site index can now be estimated for lodgepole pine stands Westwide. Furthermore, the index can be correlated with volume production.

Another approach to site predictions, using grand fir in the northern Rocky Mountains, has recently been developed. The study presents a new analytical technique to establish a rating of site quality directly in terms of growth potential rather than indirectly through the use of an index or abstract measure. With this new approach estimates of growth potential can be obtained that have 20 percent less sampling variation than those derived in the traditional manner. For a standard of comparison between species this study proposes that volume growth in cubic feet per acre per year of fully stocked stands at the culmination of mean annual increment be the criterion. Volume increase seems to be fairly insensitive to stocking at the time of culmination, so that the productivity rating would be little affected by differing stocking objectives. The application of these new methods should be the basis for better allocation of management resources among sites and forest types.

Development of equations or tables to estimate volumes, and products available in trees continue to be an important part of measurements research. Volume equations have been prepared for four species of Hawaiian hardwoods, using new methods of preparation which provide more precise estimates of volume than heretofore possible. Equations to make direct estimates of stand volume have been prepared for shortleaf pine in

Missouri. Bark correction equations have been prepared for Douglas-fir to provide more accurate estimates of wood content in trees. Traditional Douglas-fir volume tables have been reduced to equations to speed-up computer calculations of volumes. Simplified height-diameter relationships are now available for western species subject to stagnation.

2. Forest measurement

Dial-gauge or band dendrometers have been developed to measure accurately the daily and weekly changes in tree diameters for silvicultural and ecological research. Because these instruments are so extensively used, a number of improvements have recently been reported. One improvement, especially designed for small trees, substitutes a 2-point mounting platform for the standard 3-point platform used with dial-gauge dendrometers. Accuracy of growth measurement is maintained with the new platform, and it is much easier to use on small trees. In another study various kinds of band dendrometers were compared on shortleaf pine in Arkansas, with the result that improved recommendations can now be made to avoid measurement lag and to improve the design of the bands. Tests completed with dial-gauge dendrometers in the Northeast compare the precision of single versus multiple measurements on the same tree. For this test four measurements per tree appeared to be reasonable compromise between precision and practicality.

Measurement systems have also been developed to estimate characteristics of tree and shrubs other than merchantable volume in order to satisfy needs for special growth studies or forest fuel research. For example, we can now estimate the foliage and branch-wood weights of shortleaf pine for trees up to 15 inches in diameter and having a variety of crown sizes for either growth or fuel studies. Fuel weight estimators for crown and tree weight are also available for madrone, black oak, and tanoak in California. Cubic-foot volume equations and dry weight per acre predictors, used in prescribed burning research, have been prepared for hazel, a troublesome shrub growing on forest land in the Lake States.

The pioneering mensuration research unit at Berkeley, California has completed a review of tree form as a basis for estimating diameters of the hidden or obscured portions of upper stems. Various mathematical forms of equations that might be useful for interpolation and extrapolation of upper stem diameters were examined. Integrals, or summation equations, were given to convert the most useful of these stem profile equations into the primary measurement units of surface and volume. This study will improve computer-derived volume estimates that are a part of the 3-P sampling and measurement system proposed in 1963 by the pioneering unit.

3. Management planning procedures

One of the early methods to determine and demonstrate the effectiveness of various management practices was on woodlots and other small tracts of forest land typical of the locale in which they were situated. Although this method has been largely supplanted by newer experimental approaches, the demonstration forest has considerable appeal because it integrates timber-growing needs with harvesting and marketing realities on tracts large enough to be meaningful for the owners of small rural properties. The chief finding of most demonstration forests is that growing stock can be improved in quantity and quality while providing some income for the capital investment and labor of the owner. This contribution to income is important in many poor rural areas of our country. For example, over a 15-year period a pine-hardwood tract near Birmingham, Alabama, earned $2.11 per acre per year stumpage plus $1.42 per hour in labor, while sawtimber volume nearly doubled. Over an 18-year period a longleaf pine tract near Brewton, Alabama, earned a net return of $3.75 per acre while sawtimber volume increased by one-third. The best known tracts of all, the farm forestry forties at Crossett, Arkansas, have completed nearly 30 years of management and measurement. Growing stock has increased by 50 percent on the "good" forty and more than doubled on the "poor" forty. The value of products delivered to the mill over the 30-year period has been about $650 per acre for the "good" forty and $490 per acre for the "poor" forty.

For another demonstration forest, this one a 600 acre mountain hardwood tract on the Fernow Experiment Forest in West Virginia, not only were past costs and returns presented, but future costs and returns were estimated in order to choose among various timber management alternatives. The forest first came under management in 1958 when 2.7 MBM per acre were removed, and about 14 cull hardwoods deadened per acre. Cuttings are planned in 1977 and 1983. With a continuation of the present management plan the tract can be expected to return about 4.5 percent on invested capital for its first 25 years of management and 4.2 percent thereafter. However, had the first cut been 3.7 instead of 2.7 MBM the tract would have yielded 5.2 percent for the first 25 years and 4.7 percent thereafter. Methods are given in the study to explore other alternatives for achieving greater rates-of-return on invested capital in the 600 acre forest.

Periodic thinning is a standard practice in red pine in the Lake States. Traditionally these thinnings removed smaller trees from below. However, these low thinnings are frequently uneconomic, and many land managers would prefer to thin from above (remove larger trees) if they felt they

could do this without sacrificing future growth and value. In two red pine experiments in Minnesota, no important difference in net basal area growth or cubic-foot volume growth could be found between thinning from above, below, or a combination of above-and-below. An economic analysis showed, however, that whenever board-foot or cordwood value increases with tree size, thinning from below provided a greater rate of return on invested capital than does any other method or combination of methods. Thinning from above can be accepted biologically, but as a general rule it must be rejected economically. Thinning from below may result in slightly lower income at the time of the first thinning, but it will maximize average and total returns over a full rotation.

Cost effectiveness, operations research, or systems analysis, are among the names applied to groups of techniques aimed at improving the efficiency of management and management planning. Rapid increases in the use of these methods are expected at all levels of public and private management. An example of one such analysis was completed for forest sampling methods involving a choice between circular plots and Bitterlich points. The analysis, by computer simulation, was performed for five tracts whose population parameters were known. In all cases point sampling was about twice as efficient as plot sampling for estimating basal area and volume. Plot sampling, on the other hand, was twice as efficient as point sampling for estimating numbers of trees. In a follow-up study the costs of using one or the other sampling method were determined, with the consequence that the manager could develop a set of trade-offs between the two systems to achieve the most effective system for his purposes.

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C. FOREST GENETICS

Problem

Genetic improvement of forest trees is one of the most promising approaches to increasing the efficiency of timber production, improving timber quality, and reducing pesticide hazards. Trees bred for rapid growth, good form, desirable wood quality, and pest resistance are urgently needed in reforestation programs. The research job is to determine the degree of inherent variation in important traits, to develop effective hybridization and breeding schemes for improving these traits, and to devise the most efficient techniques for producing and propagating superior types of trees.

USDA and Cooperative Programs

This is a continuing, long-term program of tree breeding. It involves basic studies of genetics, breeding, and plant physiology. Superior phenotypes are selected and bred, and their progenies are evaluated to determine the genetic work of the selected parents. Outstanding trees are propagated in orchards to produce improved seed. Hybridization is attempted between varieties and species. Any hybrids produced are evaluated, and desirable ones are produced in quantity. Ionizing radiations are used to create new forms of variation. Desirable mutations will be incorporated into useful new tree varieties. Physiological studies facilitate tree breeding by developing methods of vegetative propagation, methods to overcome genetic incompatibility, and methods to assure early and abundant seed production. Other studies seek to explain the physiological mechanisms involved in desired traits like faster growth and resistance to cold, drought, and pests. Research on the identification, classification, and distribution of species and hybrids of forest trees also is included. The application of genetics research to increasing the yield of oleoresin is reported under Naval Stores. The improvement of sugar maples for quantity and sugar content of sap is reported under Maple Sap Production.

The program is carried on principally at three Institutes of Forest Genetics at Berkeley, California; Gulfport, Mississippi; and Rhinelander, Wisconsin. Additional genetics-related research is conducted in Oregon, Georgia, New Hampshire, Vermont, Illinois, Idaho, Florida, Louisiana, and Arkansas. The program involves cooperative research with numerous State agencies, universities, forest industries, and private foundations.

A grant to Yale University is providing information needed to develop pines resistant to the destructive sawflies. Another grant to Rutgers University provides for the basic research needed to propagate superior varieties of black walnut and other high value hardwoods. A grant to Pennsylvania State University supports studies of the basic mechanisms of resistance of white pines to the destructive white pine weevil. A recent grant to the University of Texas will finance basic studies of ecotypic variation in sweetgum especially the source responses to environment. In addition, grants for basic research in genetics and breeding are in force under Public Law 480 in Finland, Poland, Yugoslavia, Colombia, Italy, Israel, India, South Korea, Spain, and Chile. Some early results from these studies are described in the appropriate sections. The annual scientific effort directed to this research by the Forest Service is about 35 man-years.

Program of State Experiment Stations and Schools of Forestry

A total of 98.9 scientist man-years is devoted to this area of research.

Progress -- USDA and Cooperative Programs

1. Inherent variation

A zone of optimum environment seems to occur in the north-central portion of the slash pine range (north Florida-south Georgia), within which trees are both phenotypically and genetically superior in growth rate in comparison with trees from less favorable areas. Seedlings from this region give good early survival when planted practically anywhere in the species range and are likely to grow more rapidly than seedlings from most other sources. Seed should not be moved great distances from south to north, however. Most slash pine traits show definite geographic patterns that are usually characterized by gradients existing between extreme types located at fringes or within interior portions of the species range. This information can now be used as a guide to seed collections in slash pine and as an aid to distribution from seed orchards.

Slash pine has two varieties which merge in south central Florida. South Florida slash pine has been generally considered to be of higher density than typical slash pine but it was not known whether the difference was due to genetics or environment. A comparison made of 11-year-old trees of the two varieties growing together on a south Florida site shows that the high specific gravity is associated with environment and not genetic difference. On a related study a comparison of 9-year-old trees has shown that the

typical variety from north Florida has outgrown the native south Florida variety and also survived better. These preliminary results indicate that landowners in south Florida should consider planting the typical variety. However, it may be more susceptible to cattle damage and fire than the native variety and these factors should be considered.

Ten-year data from 15 sources of loblolly pine grown in 13 widely separated plantations over the South display well-defined patterns of variation. Results show that coastal sources can be moved inland a limited extent and that western sources tend to be more resistant to fusiform rust and survive best. The results of this study help foresters define more closely the limits within which tree seeds can be moved safely and will provide guidance in distributing seed of improved strains from seed orchards.

In another study, individual progeny were kept separate from 11 parent trees of loblolly pine from each of three stands in Georgia. While there were important differences between the stands represented, the greatest differences were between families within stands. Particularly of interest were the disease infection data. These progenies were planted in an area of extreme hazard to fusiform rust and the best families had from 4 to 6 times as many rust-free trees among them as did the poorer families. These results strongly support the present approach to breeding southern pines through plus-tree selections and seed orchard establishment.

In a species which can be vegetatively propagated for planting, such as cottonwood, there is opportunity to take full advantage of all the genetic potential of a tree. At Stoneville, Mississippi, study was made of the inheritance of height, diameter, specific gravity, and fiber length in 25 families of cottonwood. All traits are under strong genetic control and tree diameter and fiber length were positively correlated, thus selection for rapid growth will give a concurrent gain in fiber length. Specific gravity was independent of other traits observed. In another study of cottonwood it was found that under natural stand conditions, there was little difference in mean specific gravity between stands or areas in Mississippi, but there were appreciable differences between trees within stands. This means that tree breeders can select for specific gravity in the best cottonwood stands available without concern for location.

Results of 8-year-old progeny tests in slash pine near Macon, Georgia, have shown some of the potential gains to be expected from tree breeding. Superior progenies were found for individual tree heights, diameters, resistance to fusiform rust, and tree volume. The seven best progenies produced an average of 81 percent more volume than the best of several check

lots of commercial source. In a similar test of 5-year-old controlled crosses, there was a very strong relationship of progeny height to the mid-parent height, and reciprocal sets of crosses performed the same. These studies have substantiated several assumptions upon which tree improvement has been built in the South: (1) Seedlings from seed collected by the public without control can be expected to produce trees of generally poorer form, slower growth, and higher disease susceptibility than those from selected parents; (2) substantial gains can be achieved by selecting parents for form, quality, disease resistance, and growth rate; (3) the present procedure of evaluating southern pine selections by comparison with neighboring trees is valid.

Progeny tests for breeding evaluation of parent trees is an expensive and time-consuming process. It has been determined that for western white pine an estimate of general combining ability for blister-rust resistance can be obtained by making a single set of crosses using a mix of 10 or more pollens instead of the usual procedure of making 4 sets of single crosses. This finding means that only about one-fourth as many pollinations are needed and consequently the numbers of seedlings to be grown are also reduced.

Southern fusiform rust, Cronartium fusiforme, is the most serious disease attacking slash and loblolly pines and in areas of high incidence becomes a limiting factor in their management. In these areas resistance to fusiform rust is the most important single characteristic considered in breeding improved strains of these species. Studies at Gulfport, Mississippi, have shown resistance to rust to be strongly inherited and that a number of resistance-transmitting parents can be found. Crosses between the better slash pines gave progeny with only 10 percent infection after intensive disease inoculation in contrast to the 90 percent infection of woods-run seedlings.

In another study, after 10 years in the field, there were significant differences in rust infection and height in south Mississippi plantings of slash, shortleaf, and loblolly pines from 11 seed sources. Slash was tallest and most infected; shortleaf shortest with no rust cankers; and loblolly was intermediate in both traits. Loblolly pines from seed collected west of the Mississippi River were more resistant to fusiform rust than eastern loblolly, further evidence that western loblolly is an important source to consider. This knowledge of the genetic control of disease resistance is being put to use immediately by tree breeders to produce improved strains resistant to southern fusiform rust.

The larvae of cone moths (Dioryctria spp.) are a major destructive agent to seed crops in southern pine orchards. They also damage stems and branches by tunneling in the phloem. Observations over a 3-year period at Olustee, Florida, have shown a consistent and wide difference in cone infestation among individual slash pine trees, ranging from 13 to 38 percent. Stem infestations in 4-year-old progenies ranged from 0 to 27.5 percent and from 2.5 to 32.5 percent in two adjacent plantations. In a clonal plantation infestation ranged from 0 to 42 percent. The ranges of variation and the consistent performance of material is indicative of strong genetic control of this trait and points to the possibility of selection and breeding for resistance to this insect.

In other work, resistance to insects has been associated with qualitative and/or quantitative differences in oleoresin composition. A study of three sources of inland Douglas-fir has shown that quantitative differences in monoterpene composition of oleoresin are present and that these differences are associated with attack by Douglas-fir beetle. Related work with western white pine has shown that monoterpene concentrations are independent of climate and site characteristics. Examinations of six monoterpenes among 9 clones, their self progeny, and 17 F_1 crosses among them has shown broad-sense heritabilities of monoterpene levels ranging from 38 to 94 percent and narrow-sense values to be similarly high except for camphene. A detailed examination of 3-carene concentration among 28 progenies indicates that its concentration is controlled primarily by a single dominant gene; an inhibitor gene may also be involved. Knowledge of the mode of inheritance of monoterpenes can help clarify and confirm interpretations of data on these substances for taxonomic purposes, for studying biosynthetic pathways, and for seeking explanations of pest resistance attributes. Planned breeding for insect resistance will rely on these data.

Under a Forest Service grant to Pennsylvania State University a method for testing resistance to white pine weevil is being perfected. The ability to screen small trees will be of great value in hastening the development of weevil-resistant white pines. There are three favorable indications that this approach is feasible: (1) The behavior of the insects during the host findings and feedings was typical; (2) the weevils were able to discriminate among three species, in terms of both feedings and larval infestation; (3) useful levels of selection appear possible. Refinement of this procedure for use under nursery conditions will permit exposure of seedlings to feeding five times and larval infestation twice over a 2-year period.

Jack pine seed were exposed to several levels of irradiation by X-rays. Dosages of 400R were lethal to all seedlings by the end of one year. About 30 percent of those produced from seed given 1000R survived two growing seasons. Cone development and seed yields were reduced in the irradiated trees to about 10 percent in cross-pollinations and 5 percent after selfing. Studies of chlorophyll deficiencies and other mutant characters in the selfed progenies indicated that such potential genetic markers can only be accurately determined by detailed study of extremely large progenies. A study of plant radiosensitivity in jack pine has determined DNA per cell, nuclear volume, and the mitotic cycle time. Radiosensitivity predictions based on DNA and nuclear volume are unreliable. The long mitotic cycle is indicated as a possible explanation of the high radiosensitivity in this species and perhaps other gymnosperms.

Simply inherited marker characteristics are of value to geneticists to study relationships among individuals and to serve as an index of natural cross-pollination, pollen contamination, and selfing. Several studies reported this year describe the inheritance of such characters. In slash pine characters of seeds have shown high heritabilities; speckling of seed coats and seed wing striping seem to be controlled by two genes and one gene respectively. In Douglas-fir, cotyledon number in seedlings was found to be strongly inherited, thus making it possible to verify hybrid crosses immediately after seed germination.

2. Hybridization

Longleaf and slash pines are two species of major importance in the South, but each has some drawbacks; slash pine is susceptible to fusiform rust and longleaf has an indefinite juvenile "grass stage" which is prolonged by the brown spot needle blight. The hybrid between these species shows promise of overcoming both problems. It is a well formed tree, resistant to both diseases, initiates height growth immediately, and is intermediate in height between progenies of the two parent species. The best of the hybrid families produced and tested in Louisiana grew as well as slash pine, the faster growing parent, and equalled the best parent in resistance to each disease at 7 years of age. Selection of individual parents is critical to insure the optimum combination of desirable traits. This hybrid has potential use in certain problem areas in the mid-south where disease incidence limits intensive timber management.

The pines of the United States represent several major taxonomic groups and within some groups the relatedness seems distant, thus making it difficult

to produce hybrids between many species. Hybrids have only recently been made among member species of one such group, the big-cone pines of California. Most species of our pines have one or more traits of importance to long-range breeding efforts that can be transferred among species only by hybridization. The establishment of the relationships among species and the potential for hybridization make it possible for the tree breeder to work effectively with some of the heretofore limited species. A recent study shows that by using Jeffrey pine as a bridge, genetic material may ultimately be transferred from ponderosa and its related species into Digger, Torrey and Coulter pines to improve these now relatively unimportant timber species.

The major factor limiting the use of hybrid pines is the difficulty of mass-producing seed. For experimental purposes it is feasible to produce a few hundred seed by hand pollination, but the expense becomes prohibitive where large quantities of seed are needed for extensive plantations. In an attempt to mass produce shortleaf x slash pine hybrids in Louisiana, slash pollen was collected in bulk and dusted on shortleaf flowers with an insecticide duster in the hope of producing hybrids without the expense of placing pollination bags over each flower. The resulting seed were about 11 percent hybrids, varying by individual female parent from 1.2 to 21.5 percent. It thus appears that by screening shortleaf parents for hybrid compatibility, it may become economically feasible to mass produce this hybrid in an orchard situation where pollen dusting could be done on a large scale.

A test of two mahogany species and their hybrids on a variety of sites on St. Croix, Virgin Islands, shows that after 7 years bigleaf mahogany and the hybrids are significantly taller than small-leaf mahogany. The hybrids have survived better than either parent; bigleaf had the poorest survival.

3. Methods used in tree breeding

A fresh, new approach to breeding programs for Douglas-fir was developed based largely on known performance patterns of tree families in a half-century-old heredity study. The program starts with the selection of several hundred accessible cone-bearing trees and the collection of seed from the best third of these trees to be used for future planting operations. Initial improvement is based on parent-progeny correlation from phenotypic selection. A progeny test of wind-pollinated seed from all selected trees will provide the key to progressive and certain improvement through identification and choice of genetically superior parents at periodic intervals. All selected parents will be protected and available to develop whatever kinds or combinations of products may be desired. Breeding among the best parents will begin as soon as they are identified by test results. A pilot trial of the

program has been started on the Stamm Tree Farm through cooperation of the Crown Zellerbach Corporation.

Inbreeding has long worried researchers attempting to estimate genetic variances because of the risk of unknown relationships between individuals within populations. We have shown that inbreeding can take several forms among forest trees and the effect of mating among relatives was traced. The additive genetic variance itself, as well as the coefficient in the estimating equations, is biased if inbreeding exists. An overestimation of the additive genetic variance will occur most often, though some variability in response is expected. The estimation of genetic variance from potentially inbred materials is, therefore, cautioned against and remedial steps are suggested for future experiments.

An important biological problem is to recognize the flow of genes between populations, particularly between species which intermingle and may hybridize naturally. Such gene flow may explain some of the geographic variation in traits, such as resistance to southern fusiform rust. In order to study such introgression among races and species a technique is needed for determining the proportions in which the germ plasms are mixed. Several methods were investigated: principal components, canonical correlation vectors, discriminant functions, hybrid indices, and a proposed distance analysis which proved least sensitive to bias caused by unsatisfied assumptions. When the various methods were used on a set of data from introgression of two pine species, the failure to satisfy the assumptions of some methods lead to differences in biological conclusions. These results are primarily of interest to other researchers and to tree breeders.

Efficient controlled pollination methods are fundamental to large-scale tree breeding efforts and effective genetics research. One problem frequently faced is that of having to store pollens one or more years. In studies at Placerville, California, pine pollen has been used successfully after 5 years of deep-freeze storage. There was no effect on seed yields after one year of storage but pollen stored longer yielded progressively few seeds with increased storage. In most instances pollen needs to be stored only one year, but where necessary it can be stored for longer periods.

The problems of handling hardwood pollens are more acute than for pine. Yellow-poplar pollen loses all viability within two weeks after anthesis unless stored under proper conditions. This restricts the time it can be used for controlled pollinations and prohibits transport over long distances for use by other breeders. Results of vacuum and low-temperature (5°C.) storage demonstrated that viability could be retained for as long as one year.

Low-temperature storage will permit use of the pollen throughout the 2-week flowering period with the assurance of getting good seed set. Vacuum storage offers the additional opportunity of long-distance pollen transport without refrigeration, while retaining moderate pollen viability. This will greatly facilitate exchanges of material among geneticists and breeders working with yellow-poplar.

To plan breeding programs effectively, a measure is needed of the expected yields of seed from controlled crosses. Cone and seed yield results were compiled from various field stations in the South over a 10-year period. They showed that survival of cones from cross-pollinations was less than 40 percent, seed yields per cone about half those from wind pollinations, and interspecific crosses generally less productive than intraspecific pollinations. Tabular data are presented to assist breeders in selecting the correct size of effort needed to recover a given amount of seed. Even more important it pointed out the need for investigation into ways of obtaining more seeds per unit of effort.

Although spacing is a primary factor of acreage yields, and one of the forest manager's basic variables, little research has been conducted on genetic variability in space efficiency. A major difficulty has been the lack of an experimental design which would efficiently estimate the parameters of space-response curves. Modifications of the designs recently introduced by Nelder were found to provide these and are recommended for genetics and other silvicultural experiments. These circular designs are more efficient than standard designs and provide unbiased data for estimating response curves, even under conditions of limited replication.

The world botanical literature has hundreds of articles relating to resistance to fungal diseases in plants. As a first step in beginning work on the physiology of resistance to southern pines to fusiform rust, the world literature has been reviewed. It provides a sound basis for the initiation of new work and insures against repeating work done previously. This review has been published as a service to scientists in all plant fields who are concerned with disease resistance.

In cooperation with the Committee for Southern Forest Tree Improvement, and as a service to scientists and foresters, the Forest Service has compiled and published a directory of forest genetics and tree improvement research in the South. All research activities by all agencies are listed and cross-referenced by species and subject. This directory will improve coordination and help eliminate duplication in research.

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D. TIMBER-RELATED CROPS

Problem

The forests of the United States produce a number of timber-related forest crops, some of which are sources of important industries in different parts of the country. These products include naval stores, maple sap, Christmas trees, and a group of minor crops composed of edible, medicinal, and decorative materials. Some of these crops, independently or in combination with timber production, greatly enhance the total income of forest owners. These crops also provide a ready cash income which is not easily obtainable from periodic timber harvests. Many of the minor forest crops provide supplemental income to individuals in low-income areas. The research problem is to determine the potentialities of these timber-related forest crops and to develop the most efficient methods for their production.

Another important area of research is to develop better types of trees and cheaper and more effective methods for establishing, maintaining, and improving shelterbelts on the Great Plains. Shelterbelts and other special-purpose tree plantings ameliorate the local climate and improve the quality and apperance of suburban and rural environments.

USDA and Cooperative Programs

The present program of Forest Service research in timber-related crops includes a project in naval stores production and related tree improvement research at Olustee, Florida, a project in the production of maple products and related tree improvement research at Burlington, Vermont, a project on production of Christmas trees and other timber-related crops from Appalachian forests at Berea, Kentucky, and a small amount of research on Christmas tree production conducted as part of silvicultural and genetics projects in Michigan, California, and elsewhere. Shelterbelt research is located at Bottineau, North Dakota, and Lincoln, Nebraska.

The naval stores research includes fundamental studies of the physiology of oleoresin flow and applied research on the improvement of gum extraction techniques. The extraction phase of the research will be coordinated with equipment development research in the forest engineering project of the Forest Service at Auburn, Alabama. The research on maple sap production involves studies of physiology of sap flow, maple orchard management, and

the development of strains with higher sugar content and sap yield, all in cooperation with the University of Vermont.

Research on Christmas tree production includes the development of types of trees better adapted to Christmas tree use, as well as intensive cultural methods for diverse species, sites, and markets. Research on the miscellaneous timber-related crops such as greens and medicinal plants centers on ways to increase the supplemental income to forest owners.

Research in shelterbelts includes the selection and breeding of trees for better form and greater resistance to the severe climates. It includes techniques of planting and cultivation leading to higher survival rates and more rapid juvenile growth. Methods of maintaining the vigor and density of the shelterbelts over long periods of time are also under study.

Forest Service research in these fields is closely coordinated with the naval stores and maple sugar processing of the Southern and Eastern Utilization Research and Development Divisions of the Agricultural Research Service. Some phases of the Christmas tree and maple sap production are studies by State agencies and universities often in cooperation with the Forest Service. Shelterbelt research is coordinated with work of the Crops Research Division and the Soil and Water Conservation Research Division of ARS and with work of the State Experiment Stations through the Windbreak Research Committee of the USDA, and Research Subcommittee of the Forestry Committee of the Great Plains Agricultural Council.

A grant to the University of Vermont provides for basic research of the enzyme systems responsible for the interconversion of sucrose, starch, and hemicellulose in selected sugar maple trees. A grant to the University of Georgia provides for study of the resin acids from oleoresin and their relationship to naval stores production.

The annual Federal scientific effort devoted to the research by the Forest Service is 18 professional man-years.

Program of State Experiment Stations and Schools of Forestry

A total of 4.5 scientist man-years is devoted to this area of research. Of this total 0.2 is in naval stores, 0.8 in maple sap, 2.2 in Christmas trees and 1.3 in shelterbelts.

Progress -- USDA and Cooperative Programs

1. Naval stores

An exploratory study at Olustee, Florida, has shown that slash pine trees vary greatly in the chemical makeup of their turpentines. Differences occur not only among trees within stands but also among stands growing in different portions of the species range. The differences, furthermore, are inherited to a rather large degree. The results suggest that we can breed strains with improved gum quality. For example, through selective breeding we can develop a strain that will produce 10-20 percent more of the most valuable constituent, B-pinene. Likewise, racial differences may permit control of turpentine composition by keeping gum separate by geographic source. This information is of immediate use to the tree breeders working on the breeding of high gum-yielding strains of slash pine.

Research on slash pine at Olustee, Florida, shows that extremely high natural variation in gum-yielding ability, along with relatively strong heritability, makes it possible to attain appreciable genetics gains in this trait even when selecting from a limited population. There are no unfavorable genetic correlations between gum yield and other traits for which improvement is sought, including growth rate, stem straightness, and branching habit. These facts suggest that the best approach is to select first for the easily measured timber quality traits and then select for gum yield in the restricted population. Both the seed production area approach and the clonal orchard approach are being used. About 15 forestry organizations have made their plus-tree selections (selected for traits other than gum yield) available for use in the program on breeding high-gum-yielding pines.

Research supported by a PL 480 grant to the University of Chile is determining the metabolic pathways through which monoterpenes are formed in pines. Using radioactive labeled mevalonic acid, the various intermediate compounds in terpene biosynthesis have been identified in Pinus radiata. Fundamental to any effort to increase the production of oleoresin is an understanding of how the tree produces it. Further research on the physiology involved should lead to new means of stimulating gum flow.

2. Maple sap production

Sugar maple has in the past received little attention in research on seed handling and nursery practices. Studies at Burlington, Vermont, have shown that any of several stratification-germination media (sand, perlite,

sphagnum moss, and germination paper) were equally effective for sugar maple seed, but germination paper in plastic boxes was most efficient. Germination began during the sixth week of stratification at 33° - 35°F., and was nearly complete at the end of the 90-day cold period. As planting increases and we look forward to the production of improved trees for sap yield, we now know how to handle the seed to obtain maximum germination and to get reliable seed tests for nursery sowing rates.

As we gain experience in sugar maple seedling production, we continue to meet new and unexpected problems. The larvae of an anthomyiid fly (Hylemya florilega Zitt), known to cause widespread damage among horticultural crops, was found to have destroyed as much as 70 percent of our spring-sown seed. This problem has been serious in only 1 year so far, and as yet we do not know how important the insect may be in the growing of sugar maple seedlings in nurseries year after year.

Taphole depth is an important factor in sap yield of sugar maple. By local custom throughout the maple region, the majority of tapholes are drilled to a depth of 3 inches or less, including the thickness of the bark. Drilling to a fixed depth reduces productive depth of the tapholes by an amount equivalent to the thickness of the bark, which was found to vary from 1/4 to 1 inch. Allowing for bark thickness and drilling holes to a depth of 3 to 3-1/2 inches in clear wood can increase sap yields by at least 10 percent. Potential increases of this magnitude should be important to all producers who currently disregard or are not aware of the variation in sugar maple bark thickness and its possible effects on productive taphole depth.

3. Shelterbelts

Systems of tree windbreaks can ameliorate for agriculture the adverse environments of dry, windy regions of the world. Patterns of tree belts reduce wind movement and create sheltered zones with microclimates different than open, unprotected lands. This kind of forestry must be planned ahead and established along with other soil and moisture conservation practices. Growth curves provide the information on maximum effective height needed by windbreak technicians to specify spacing intervals between windbreaks. Fifteen 22-year-old field windbreaks in different climatic areas of Nebraska and Kansas provided curves of height growth rates of Siberian elm. Extrapolation of growth curves indicated Siberian elm in Nebraska windbreaks may reach maximum height at 32 to 36 years, but height growth may continue slightly longer in Kansas. Siberian elm is likely to deteriorate within the next decade after it reaches maximum height. It is important that shelterbelt owners understand this and take action with silvicultural practices that can forestall this early decadence.

Suppressed ponderosa pine and eastern redcedar in 25-year-old shelterbelts in eastern Nebraska responded with increased vigor and height growth when adjacent rows of overtopping Russian-olive and green ash were cut. In addition, if stumps of cut trees were allowed to sprout, resulting foliage improved lower-level density of windbreaks. Stumps of Russian-olive, however, should be deadened with herbicide because regrowth was rapid and caused continued competition with conifers. As the shelterbelts from earlier programs, such as the Prairie States Forestry Project, increase in age, action must be taken to keep them healthy and to provide for future replacement after they pass maturity. Silvicultural practices can improve vigor, longevity, and effectiveness of windbreaks. If shelterbelt owners will apply these practices, many miles of presently suppressed conifers can be rejuvenated to increased growth and vigor. In addition, the effective lower-level density of these field windbreaks will be improved and thus provide greater sheltering effect for soils and crops.

4. Other

As an aid to landowners, including those in a part of Appalachia, a comprehensive bulletin on Christmas tree production has been prepared in cooperation with the Kentucky Agricultural Experiment Station. This bulletin discusses all aspects of Christmas tree production from the preliminary planning through the various cultural practices to harvest. At present, Kentucky has very few growers producing high-quality, plantation-grown Christmas trees. There are many suitable sites available where farmers and other landowners can, without a large cash investment, convert idle and unproductive land into a source of additional income by planting and raising Christmas trees. Christmas tree culture has potential for contributing greatly to the rural economy of that area.

Christmas trees should be planted in an upright position, but even experienced tree planters sometimes carelessly set a few seedlings in a leaning position. This results in lower quality and cull trees with crooked stems. Survey of a 1-year-old plantation showed nearly 12 percent of the trees had been planted in a leaning position. Improper planting and the losses associated with it can be prevented or at least greatly reduced by thorough training in the proper procedures and adequate supervision during the planting operation.

Results of a test of Scotch pine from throughout its natural range can be used as interim recommendations of best seed origins for Christmas tree plantations. Use of origins that combine good coloration during winter with rapid growth can earn Christmas tree growers thousands of extra dollars. Five- to seven-year-old plantings in the north-central states, including Nebraska, showed large differences among provenances in height growth, foliage color, needle length, winter injury, and susceptibility to insects. Fastest growing trees in all plantations came from central Europe. Slowest growers were from the most northerly latitudes of Siberia and Scandinavia. Trees from northern latitudes turned very yellow during winter, but winter injury occurred only on stock from Spain. Origins showing best winter foliage color in Nebraska were from the Vosges Mountains, France, northern Italy, and northwestern Turkey. Christmas tree growers should be careful to specify the seed source for planting stock purchased. Nurserymen can now specify proper sources for purchased seed to insure production of high quality stock that will provide the grower with maximum returns in high quality trees.

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II. WATERSHED, RECREATION, AND RANGE RESEARCH

A. FOREST SOIL AND WATER RESEARCH

Problem

All of the major rivers of the United States have headwaters in forests, associated rangelands, or alpine regions. Although these forest lands cover only one-third of the total land area of the conterminous United States, they yield two-thirds of the waterflow of the country. The management of these areas is a major factor in determining whether this waterflow is beneficial or harmful, whether it is a well-regulated, sustained flow or erratic with alternating floods and dry channels, and whether it is clear or silt-laden. To derive the greatest benefits and protection from these headwater areas, improved knowledge of the management of watersheds and streams is needed.

Present water demand for domestic, industrial, and agricultural uses is estimated to be about 300 billion gallons per day. Although much of this water is returned to streamflow, shortages already exist. Future demands call for reasonable increases to about 470 b.g.d. by 1980--an increase of more than 50 percent--and to about 700 b.g.d. by 2000. The most logical place to look for additional supplies of high-quality water, or to improve timing of streamflow, is in the headwaters. At the same time, there are constantly increasing pressures to use watershed lands for a variety of other products and services. Additional research is needed to determine the best means of adjusting these several uses to protect and develop soil and water resources.

USDA and Cooperative Programs

This work includes basic and applied research into the relationships of soil, climate, vegetation, and water and the development of methods and techniques to: (1) increase water yields or improve the timing of such yields under a variety of climatic, soil, geologic, vegetative, and topographic conditions; (2) give adequate protection to soil and water resources while forest and related range lands are being used for timber production, grazing of domestic livestock and big game, wildlife habitat, mining, and forest recreation; (3) rehabilitate forest and related range land watersheds that constitute sources of damaging flood runoff and sediment; and (4) aid forest soil development and improvement. Nationwide, 86 man-years of scientific effort were expended by the Forest Service on this research in the past year.

Program of State Experiment Stations and Schools of Forestry

A total of 36 scientist man-years is devoted to this area of research.

Progress--USDA and Cooperative Programs

1. Water yield improvement

Research in the improvement of water yield is conducted in the different terrain, climatic, and forest vegetational complexes throughout the Nation. The purpose is to explore the opportunities for improving the amount and/or timing of water yield through manipulation and management of the Nation's forested and related range and alpine watersheds. Water yield improvement research is being done in (a) alpine snowpack zones of the West, (b) forested snowpack zones of the East and West, and (c) in nonsnow forest areas. Research results are discussed under these subdivisions.

a. Alpine snowpack zone. The alpine zone includes the area above timberline. The climate is cold, and winds move the snow about continuously. Snow cover is seldom over 2 feet deep except for protected pockets in ravines or behind obstructions where the snow may drift to depths of 30 feet or more. The drifts melt slowly and last well into the summer, maintaining streamflow long after ordinary snow accumulations and lower elevation snowpacks have melted. Thus, a snowpack may be considered a natural reservoir, from which there is comparatively little evaporation. There are approximately 5 million acres of alpine area in Colorado and Wyoming. About 10 to 20 percent of these alpine acres have snowfields that remain during the summer months and contribute to summer streamflow. Flow regulation should be very important to those water users served by direct diversion from streams above reservoirs.

There are over 2 miles of snow fences in one watershed in Colorado erected for the express purpose of inducing more deep drifting to increase late-summer streamflow. Sections of these fences have been damaged by snow accumulations. Drifts to the windward of other sections have reduced their effectiveness. These two new problems--improved fence design and fence location--are still subjects for additional research.

Forecasting and control of snow avalanches are other aims of alpine snow research. Generally, the objective of avalanche control is to minimize the hazard of avalanche destruction, but now it appears possible to derive a positive benefit from avalanches. The piles of snow at the foot of avalanche paths also make good supplies for late-summer streamflow. If avalanches were released intentionally two or three times during the winter, large amounts of snow could be piled up. As most of the snow in an avalanche area is the result of wind deposition rather than direct snowfall, the avalanche areas will act as effective snow traps when empty.

A powder avalanche near Berthoud Pass, Colorado, moved a 7,000-pound truck 60 feet horizontally and dropped it 50 feet into a gully without serious damage. The avalanche was intentionally released by artillery fire while the truck was parked off to the side away from the path of the avalanche. Thus, the truck was moved either by a blast of air set up by the avalanche or by a slower moving mixture of powder snow and air. Either force could have been

responsible, with velocities computed from the forces needed to move the truck: 160 miles per hour for the snow-free air, or only 64 m.p.h. for a snow-air mixture of reasonable density. This is an interesting event that will be useful in developing a theory to explain the dynamics of snow avalanches.

b. Forested snowpack zone. Below the alpine area lie the forested and brush watersheds which accumulate snow and supply much of the streamflow of the western mountains and at lower elevations in the north and northeastern sections of the country. In the West, excellent opportunities prevail for improving water yields from the snowpack zone through management of the forest vegetation. Annual precipitation averages 30 to 50 inches of water, of which 14 to 22 inches appears as runoff. Preliminary studies of cutting patterns and other forest management practices which reduce interception and evaporation losses and increase the snowpack indicate possible increases in water yield as much as 4 inches. Little is known about the effect of various forest densities, cutting patterns, slope direction, and climatic characteristics upon snow accumulation, ripening, and melt.

Solar radiation is one of the most important climatic factors affecting the disposition of snow and evapotranspiration from forest stands. Until recently, radiation measurement was a rather uncommon thing, mainly because of the high cost of instrumentation. Now, less expensive radiation sensors and recording systems have greatly increased the interest in solar radiation. One of the first things to be determined is the variability of solar radiation over forest land.

Variation was found to be relatively slight over a uniform hardwood stand at the Hubbard Brook Watershed in New Hampshire. The magnitude of radiation variability was only 6 percent, but it ranged up to 20 percent when other cover types are included. This means that a measurement of light energy at one point above a uniform forest will be close to the average value for the whole forest.

But in regions where there are rapid climatic changes, such as in the Cascade Range of Washington, single station measurement over even short distances may be suspect. Here as many as 10 instruments were used in a 40-mile-square area, and this number was adequate only on very clear or very cloudy days. This one million-acre area contained many individual forest stands, of course, and it is estimated that a network of 100 or more sensors would be necessary to determine reliable mean values of radiation on days of variable cloudiness.

Using a specially constructed aerial tramway, variation in albedo--the ratio of outgoing to incoming solar radiation--was measured over a 40-year-old red pine canopy in New York State. Albedo varied from a high of 0.20 when the canopy was snow-covered to a low of 0.08 during the spring months. Variation along the tramway ranged from less than 1 percent to 20 percent; the greater variation generally occurred at low sun angles. These data will be useful in future studies and in calculations of the forest energy budget.

Melt rates of spring snow have been increased two to three times by the use of carbon black in Colorado mountains. Snowmelt acceleration is used in foreign countries to benefit irrigation and hydroelectric power systems. It is used in this country to hasten snow clearance from roads and other areas. Carbon black effectiveness increases as the particle size decreases, but the larger particle sizes are cheaper. Other black materials, which will absorb radiant energy to a greater or lesser degree, will also be evaluated for effectiveness in relation to cost.

Geophysical survey observations on three small Black Hills watersheds show promise of providing more information than expected. Two geophysical techniques--refraction seismograph, using a hammer as a shock source, and electrical resistance measurements--have shown good correlations with bore hole logs and cores. Drilling cores have been used to determine the distribution and characteristics of the watershed soil and rock mantles which, in turn, provide information on quantity and timing of water yield. Substitution of the more rapid geophysical techniques can be expected to improve predictions of watershed behavior.

Snow accumulation and rate of melt can be controlled significantly by manipulation of forest vegetation, as shown by studies in the Sierra Nevada. Snow accumulation was increased by cutting strips two chains wide and four chains wide. Openings of either size accumulated more snow than the uncut forest, with the wider strips having the greater amounts. Melt rate depended on the orientation of the strips: the rate was faster on the east-west than on the north-south orientation. Thus, to get the best combination of increased accumulation and delay of melt, a strip 4 chains wide, oriented north and south, would be cut on cold north and east slopes. The most rapid snowmelt would occur on 2 chain strips oriented east and west on the south slopes. On the latter strips, the speedup in melt is caused by the radiation of sensible heat from the north wall of timber into the snowpack to the south.

c. Nonsnow forest zone. The concept of water yield increase or change in timing of streamflow through manipulation of the vegetative cover is based largely on the fact that vegetation uses large amounts of water. By varying the density of forest stands, the arrangement of stands with respect to openings in the forest, or by converting the present cover to a new cover type, the amount of water used by vegetation may be changed. Any change in water use will be reflected in the volume of water moving through the soil to ground water and ultimately to streamflow.

In Hawaii, all water supplies relate to disposition of rainfall on mountain lands. Two small mountain watersheds on Oahu--one covered with fern and the other a forest plantation--provided a comparison of streamflow from two distinct vegetation covers. Although there may be some hydrologic difference between the two watersheds, annual streamflow was about 10 and 19 inches for the tree and fern watersheds, respectively. After this relationship was determined, the fern watershed was burned and the flow increased another 20 percent. Analysis indicated that the burning decreased interception but had

little effect on infiltration or percolation. As demands for water and land uses other than watershed protection are increasing in Hawaii, responses to alternative management practices such as this one need further research.

Almost 13 percent of the annual rainfall in the Ouachita Mountains of Arkansas was intercepted by a dense pine stand with a hardwood understory. Initially, about 15 percent was caught by the tree canopies, but an inch of this total flowed down the stems and eventually reached the ground. Both throughfall and stemflow amounts were directly correlated with the total rainfall on the storm date and were negatively related to the long-term mean temperature on that date. The effect of temperature was probably twofold; it reflected the amount of foliage present on that date and, perhaps to a lesser degree, the amount of heat available for evaporation of moisture during the storm. Stemflow was negatively correlated also with tree size. Larger pine trees have rough bark that holds moisture and decreases stemflow.

How important is interception? Quite important, according to a study in Colorado showing that intercepted water was almost a total loss. Some years ago, heat physicists conjectured that interception resulted in little or no net loss of moisture, that it merely took the place of the normal transpiration of the intercepting plant. After all, they said, there is only so much energy available for the vaporization of moisture. If some of it is used in evaporating intercepted moisture, then that amount will not be available for transpiration. Under this hypothesis, interception would cause no net loss. But, according to the findings in Colorado, the evaporation of simulated rainfall intercepted on the canopies of potted conifers resulted in evapotranspiration rates nine times greater than transpiration alone from similar plants whose foliage was not wetted. Why the difference? One answer lies in radiation differences. When a leaf is wetted, it becomes darker in color and absorbs more radiation. In the Colorado study, the amount of absorbed radiation increased 12 percent by the wetting of the foliage. But this is not the total difference. Stomatal resistance, the inherent difficulty of vapor movement from the leaf, probably accounts for the remaining difference between transpiration and the evaporation of intercepted moisture.

Measurements of radiant energy on a watershed in West Virginia reveal that about one-third more energy was used in evapotranspiration on a forested site than on a cleared site. Taken on a clear day in July, these observations help to explain differences in water yield resulting from forest cutting. The difference in net radiation between the two sites was sufficient to evaporate about 0.06 inch of water, which is very close to the 0.05 inch estimated daily increase in streamflow from the cleared watershed on which the radiation measurements were made. Thus, the cleared area retained the moisture that was not lost by evapotranspiration, and eventaully delivered it to streamflow. Most of the additional radiant energy retained on the cleared site went to heat the soil.

Radiation balance studies in Israel (PL-480) related this variable to actual evapotranspiration. From the relationship derived, evapotranspiration can be

estimated to an accuracy of about 15 percent. Rainfall was low during the past growing season and moisture withdrawal was only 390 mm. in pastured plots. In maqui-brush (chaparral) plots, moisture withdrawal was 430 mm. Deep drainage continued into mid-May.

Evapotranspiration from a peat bog in northern Minnesota exceeded potential evapotranspiration estimated by three different methods. Measurements were made at two experimental evapotranspirometers--sheet metal cylinders 10 feet in diameter driven 3 feet into peat that was almost impermeable. The hydraulic conductivity of the peat was so low that water did not move in or out of the bottomless cylinder. Total evaporative loss from the two cylinders averaged 10.59 inches from the middle of July to the end of October. The difference between the two cylinders was surprisingly small--less than 3 percent from the average. But the average was about 12 percent greater than evaporation pan measurements. It was also 12 and 24 percent greater than estimates of potential evapotranspiration by both the Thornthwaite formula and the Hamon formula, respectively. These two formulas are empirical methods of estimating potential evapotranspiration by means of climatic parameters. It is unlikely that the greater losses from the evapotranspirometers were the result of seepage. Many of the weekly amounts were lower than estimated, particularly in the cooler period when evaporation was low.

Actual evapotranspiration is not much less than potential evapotranspiration in the mountains of northeastern West Virginia. An analysis of data obtained at the Fernow Experimental Forest and applied to a computer program showed that actual ET averaged over 95 percent of the potential. The program is based largely on Thornthwaite procedures although it apparently is not as sensitive to soil moisture deficits as is the Thornthwaite method. Nevertheless, the analysis helps to explain the strong response of water yield to cutting on the Fernow watersheds. It is estimated that there was little moisture deficit--the greatest amount for any one year was 2.3 inches, a very low amount. Therefore, evapotranspiration proceeded at a high rate until the transpiring medium--the forest--was removed.

A white pine plantation is using more water than the hardwood forest it replaced. Based on records and analysis from a calibrated watershed at the Coweeta Hydrologic Laboratory in the Great Smoky Mountains of North Carolina, this is the first evidence of its kind made from a complete conversion of vegetative cover on a whole watershed. In 1957, all trees and shrubs on a 40-acre watershed were felled and white pine was planted. Hardwoods have been kept out by seasonal cutting and herbicide spraying. Water yield increased about 6 inches the first year after cutting. It gradually decreased as the white pine grew, and in 1966 streamflow was 3 inches less than predicted for the original hardwood stand. The 10-year-old plantation has a basal area of only 30 square feet per acre compared to 85 for the original hardwood stand. Thus it is likely that the ultimate difference will be considerable. An estimate of interception loss at a similar white pine plantation is 2 inches greater than that for a hardwood stand. It seems reasonable, therefore, to suspect interception as a major factor contributing to lowered water yield from white pine cover.

Evapotranspiration from the riparian (streamside) zone of an experimental watershed in northeastern Pennsylvania ranged from a low of about 50,000 gallons per day to almost 300,000 during June, July, and August months. As much as 23 percent of the daily streamflow was lost by this excessive evapotranspiration. These amounts were determined by a recently developed method of predicting riparian water loss. Samples of daily losses were obtained by examination of streamflow records. These losses were then related to mean daily streamflow and vapor-pressure deficit in a regression analysis that accounted for 76 percent of the variation in daily losses. The method provides a means of estimating the amount of water that may be saved by removing riparian vegetation.

In Appalachia, water yield may be increased in large amounts ranging from 10 to 18 inches annually by forest clearcutting. Using information from several experimental watersheds in Appalachia and relating these data to potential evapotranspiration estimates over the whole area, possible increases were calculated. Pittsburgh, Pa., with low rainfall could expect an increase of only 10 inches while Birmingham, Ala., with high rainfall might get an 18-inch increase. The analysis revealed that major differences in rainfall at any one place--as much as 17 inches--produced differences of only 1 or 2 inches in water yield.

Modern computer techniques have been devised to process streamflow records at the Coweeta Hydrologic Laboratory in North Carolina. If a punch-tape recorder is used, the whole process is automated through a translator of the punched paper tape to flow separation of the hydrograph. If the older chart recorders are used--and there are many still in use--a chart reader must be used to start the automation process. Over 400 water years have been processed by these methods at a relatively low cost. The benefits to be gained by this modern approach to streamflow data processing include greater accuracy, much more detailed hydrograph information, and a reduction in cost.

One of the benefits related to automated data processing at the Coweeta Hydrologic Laboratory is a new type of calibration made possible by computer techniques. Treatment effects can now be predicted on a monthly basis instead of an annual or seasonal basis. Monthly values show the actual timing of increased water yields and the periods of no response. The new program will permit reanalysis of past watershed studies for additional information on timing of yield changes.

2. Prevention of watershed damage

There are many thousands of acres of forest and related lands that are in good watershed condition. Increasing demand for use of these lands for timber harvesting, grazing, recreation, and wildlife requires that special attention be given to maintaining stable soils and controlled streamflow. Research in this area involves development of land-use practices that give special attention to the prevention of watershed damage.

a. Timber management. Management of forest land for timber production should not be damaging to the land surface, stream channels, or stream water. However, in some problem areas damage has occurred even when the best of the known techniques have been applied. Research must either devise new techniques that prevent damage or determine that certain areas should not be so managed. Herbicides, insecticides, fertilizers, and other chemicals are becoming standard tools in timber management but may have undesirable side-effects. Interest in these so-called pesticide effects is considerable and research is increasing.

The major flood producing areas in Oregon lie between elevations of 2000 and 4000 feet. This fact is an example of information derived from mathematical models of hydrologic processes--which also produced a map of the erosion potential of land areas to show where the greatest opportunities for flood prevention may lie, and where the greatest caution to avoid erosion must be taken. Forests of the future should be designed to meet specific objectives in water yield and water control. A knowledge of hydrologic potential--how much each unit of forest can be made to yield or produce in terms of water, flood protection, or erosion control--is basic to meeting these objectives. Use of mathematical models to obtain this information is developing rapidly.

"Historical hangover"--the lingering effects of forest disturbance on watershed condition--may cause devastating erosion and sediment delivery long after watersheds have seemingly recovered. An obvious example of the result of "historical hangover" is the removal of forest trees from sloping lands. The site is stable for 5 to 10 years, held together by the old tree roots. When they decompose, the whole slope may collapse. Although the reduced infiltration capacity after logging may still be great enough to take care of all but the largest rainstorms, any time rainfall exceeds the reduced capacity of the soil to take in water, the apparent recovery has been nullified. Rapid recoveries from watershed disturbances may be more apparent than real.

Rainfall studies on the Coulee Experimental Forest in southwestern Wisconsin have shown that the dissected terrain of the area has only a small effect on annual rainfall at any point of measurement. On a steep ridge, rain gages on the windward side caught 3 percent less rain than gages on the leeward side. The difference for the storms of 0.5-inch precipitation or more was only 2 percent. A comparison of rainfall caught by ridge and valley gages indicated that ridge gages tended to catch more, but these differences were also small. Thus, rainfall on the experimental forest varies from place to place, but the differences probably result more from normal storm variation than from topographic effects per se.

Snow cover on the east slope of the Sierra Nevada absorbs raindrop energy in a manner similar to that of dense vegetation. In a study near Reno, Nevada, soil losses from snow-covered plots were practically nil, regardless of vegetative cover. On the other hand, snow cover lowers the temperature of

rainwater falling on it and tends to preserve soil frost. Concrete frost, with varying porosity, usually reduces infiltration capacity and increases overland flow on burned or sparsely vegetated sites. It does not impair infiltration where there is appreciable plant and litter cover. Stalactite frost, formed under less sustained cold, absorbs water readily and may even improve infiltration. Floods in this area typically result from prolonged high intensity rains falling upon shallow snowpacks that often melt completely and contribute additional water to flood runoff. If the formation of concrete frost can be prevented, infiltration will be increased, overland flow minimized, and flood damage lessened.

At Fraser Experimental Forest in central Colorado most of the sediment load is derived from channel erosion. One out of three watersheds was logged in 1954 and 1955 by careful harvesting of one-half of the merchantable timber. Although sediment yields from the logged watershed were relatively large during the years immediately after treatment, they were not significantly different in a statistical sense from sediment produced in the other two watersheds during the period 1956 through 1963. Yields since 1958 have been normal even though streamflow was increased 25 percent as the result of the cutting.

Laws describing water movement in agricultural lands apparently do not apply to forested soils. Basic research in subsurface flow being carried out in Ohio has shown that water often flows rapidly through forest soils because of its root channels, worm holes, and cracks. Darcy's law, which was developed experimentally in a homogeneous porous medium under ideal conditions, breaks down when water flows through soil in nonparallel directions such as through root channels and when soils are not saturated. It is doubtful if any of the existing equations can be used successfully in such soils, but new theory and equations are needed for future hydrological and soils research.

Attempts to measure the rate of subsurface flow have had variable results. The heterogeneous medium discussed above is so variable that it cannot easily be classified or described. Now it has been found that small soil blocks can be impregnated with plastic, cut into thin sections, and examined with a microscope to determine the size and distribution of the passageways through forest soils. If successful, this technique will enable the determination of potential stormflow through forest soils.

Very little DDT passed through the 1-inch forest floor above a tension lysimeter in a Douglas-fir plantation near Seattle, Washington, even when applied on the ground at the excessively high rate of 5 pounds per acre. Even less passed through the surface soil, a gravelly sand. This is confirming evidence of the strong retention of DDT residues by the forest floor and organic fraction of forest soils; water leaching through these soils and moving into streamflow contains practically no DDT. Zectran was also applied in the study, at a low rate of 0.1 pound per acre, but the analyses were not reliable for comparison.

In a laboratory study in Oregon, a solution of Gibrel enhanced the biologic decomposition of all organic materials tested. Gibrel, a potassium salt of gibberelic acid, was added to sawdust of all major Pacific Coast tree species, to several different kinds of straw, and to other organic wastes. Results indicate that Gibrel may be a useful chemical in activating decomposition and may hasten the decomposition of logging wastes. However, the effects of the "activator" on other soil and biologic processes must first be determined to avoid any possible undesirable effects on the forest environment.

Stemflow--that portion of rainfall that reaches the soil by running down the tree stem--is about twice as rich in nitrogen as other forms of precipitation. In a study made in coastal Oregon, researchers found that total nitrogen brought down in precipitation amounted to 1.33 pounds per acre. Although not a large amount, if it were concentrated at the base of young tree stems it might have an effect on chemical or microbiological soil properties at a critical point. In older forests, stemflow is a negligible factor for a rough bark holds most of the flow. Eighty-seven percent of the nitrogen found in rainwater was in the organic form presumably derived from airborne organic debris. As stemflow picks up more dust and debris, this is the reason it is additionally enriched.

More than 70 percent of the mass soil movements in the H. J. Andrews Experimental Forest of western Oregon occurred in connection with roads. Following the Christmas week storm of 1964, a reconnaissance survey disclosed 47 mass movements comprising 347,700 cubic yards of soil and rock. Most of the road-connected events involved massive failure of cut bank and fill slopes. Damage was not always confined to the road right-of-way; these movements often triggered stream-channel scouring or other types of erosion below the roads. Seventeen percent of the mass movements occurred in logged areas. Only 11 percent were in areas completely undisturbed, but these 5 events were massive, accounting for 40 percent of the total volume of soil moved during the storm. Almost two-thirds of the events were on greenish tuffs and breccias that comprise only 8 percent of the total area. The study clearly indicates the unstable nature of the tuffs and breccias and suggests they be handled with great caution. It also indicates that man's activities, especially roadbuilding, often accelerate this form of erosion. It points up the need for additional knowledge of serious problem areas and for new roadbuilding and stabilizing techniques.

Soil creep ranges up to one-half inch annually on 40 percent slopes in the Coast Range of California. Applying to the upper 10 feet of soil and rock, this soil creep is equivalent to 4 tons annually for each 100 feet of stream channel into which it moves. Logging operations and changes in land use often drastically increase rates of gravitational mass movement both directly and indirectly. Logging roads, skid trails, landings, and general disturbance of slopes result directly in landslides and accelerated soil creep. Undercutting of slopes, changes in soil structure and soil moisture balance, and loss of tree root support are the intermediate steps. Upstream logging

operations, by leading to increased streamflow, may indirectly initiate and reactivate slides downstream.

b. Logging road location and construction. A large proportion of sediments reaching stream channels from forested lands originates from roads. In the construction and maintenance of roads, soil disturbance is inevitable. Yet, roads are a necessary part of the process of converting overmature forests to managed stands. And, as logging has pushed further into the steeper, more inaccessible forest areas, soil disturbances from road construction have increased. Procedures are being developed for minimizing erosion from road surfaces, restoring stability to fill slopes, and regaining overall absorptive capacity of disturbed soils as quickly as possible.

A combination of straw mulch and netting effectively controlled erosion on a steep fill slope of a newly constructed road in Idaho. The fill slope, having an average gradient of 80 percent, was constructed of typical problem soils of the Idaho batholith--loose, weathered, granitic material that erodes readily. Eight plots were established on this fill slope and all were seeded and fertilized except one untreated control plot. Two of the plots were furrowed on the contour, but this was an ineffective treatment; in fact, one plot eroded more rapidly than the control. The straw mulch without the netting had an intermediate effect. Three types of netting were tested: paper, jute, and chicken wire. All three were equally effective in holding the mulch in place and thereby holding the soil.

In the Northern Rocky Mountains, logging roads may be located and designed in accordance with several criteria that are readily available to forest land managers. Design factors entail spacing of cross drains and width of protective strip below the logging road. And those two design factors are dependent on the soil, the road grade, aspect of the slope, topographic position of the slope, the type of obstruction to sediment movement in the protective strip,and the distance between obstructions. A guide has been published to assist land managers in evaluating these criteria.

c. Range management. Forest-associated rangelands are a primary source of waterflow. They also provide needed forage for big-game herds and large numbers of domestic livestock. Continued grazing use of these lands is dependent upon plant cover for maintaining stability on these sites.

Fall burning in strips significantly reduced the shrub cover and the litter layer on the Sierra Ancha Experimental Forest in central Arizona. But burning also caused considerable sediment movement during the early recovery period. In August 1963, a month in which precipitation totaled 8 inches, about 0.5 acre-foot of sediment movement per square mile occurred on the burned areas, while no sediment was yielded from the unburned check. Litter reduction ranged from 24.7 to 57.0 percent, and shrub cover was reduced by 94.5 percent.

The litter mass under Pringle manzanita on the Sierra Ancha Experimental Forest will retain as much as 0.20 inch of water. Almost as much--0.19 inch--was retained by typical shrub live oak in a study of water absorption and retention by litter. Samples of litter were saturated, drained, and oven-dried. Approximately 2.00 grams of water were retained per gram of manzanita litter, compared to 1.80 grams per gram of oak litter. As oak litter is somewhat heavier than manzanita litter--12.1 tons per acre and 11.2 tons, respectively--there was no significant difference between the two communities in their water retention capability.

3. Rehabilitation of damaged watersheds

In addition to those watershed lands needing protection, there are great areas that have already been damaged by past use. Some of these damages date back many years and most of the lands remain in unsatisfactory condition. This research is designed to develop techniques and management practices to stabilize and improve soils and to restore satisfactory streamflow conditions.

a. Abandoned farmlands. In years past, the forest was cleared from many thousands of acres in the Piedmont and upper Coastal Plain of the Southeast and South and other areas in the Lake States and Central States, and the land was put under clean cultivation. Serious erosion and lowered productivity of the land have resulted in abandonment of many areas. The problems of how to stop the active erosion and how to reestablish trees and other protective vegetation on those lands are serious and difficult to solve.

The establishment of loblolly pine on bare gully slopes of the southern Coastal Plain requires mulch to immobilize the highly erosive soil, and the mulching of individual seedlings will save over $50 per acre as compared to broadcast mulching. Over 2 million acres need reforestation primarily to control erosion, and loblolly pine has emerged as the plant that meets most of the requirements for erosion control. It supplies and maintains the most effective surface cover found thus far. The improved mulching practice can be applied to 100,000 acres of gullied areas that require stabilization.

Although it has been traditional to plant loblolly pine seedlings in the South between December 1 and March 1, research results show that cold-stored seedlings can be successfully planted as much as 2 months beyond the March 1 date. Conservative estimates indicate that survival would increase 5 percent by the later planting. Late planting is recommended in all of the loblolly pine range between latitude 33° and the North Carolina-Virginia border.

More than half of the annual sediment yield of the Pine River Branch of the Manistee River in Michigan was sand-size particles. This same particle-size distribution was also found in eroding sandbanks along the stream, apparently the source of most of the sediment and bedload movement. Stabilization of the numerous eroding sandbanks should be very beneficial to the trout habitat on this stream and similar streams where movement of the sand bedload scours food organisms from the bottom of the stream, covers spawning beds, and fills

the deep pools that provide shelter. Suspended sediments, silts, and clays were of low concentrations and probably cause little damage to the fishery. Although the clay banks are eroding, they are less important than the sandbanks and will be given a lower priority in stream rehabilitation programs.

b. Damaged rangelands. Overgrazed rangelands in Western United States are often serious source areas of floodwaters and eroded material. Rangeland soils are often thin and sites are harsh. Past efforts to reestablish protective vegetation have frequently failed. Research in development of new and better procedures for rehabilitation is underway in several areas.

Summer-deferred grazing on the Rio Puerco drainage in New Mexico reduced sediment movement about 70 percent during a 5-year period. This type of grazing management entailed the exclusion of animals from the beginning of April until the end of October each year and the utilization of 55 percent of alkali sacaton forage during the winter season. The study took place on the San Luis experimental watersheds, 58 miles northwest of Albuquerque, where the average sediment loss was 0.7 acre-foot per square mile per year before fencing. Fencing was completed in 1957, summer-deferred grazing was initiated on all three adjacent watersheds, and average sediment movement declined to an average of 0.2 acre-foot per year. In addition, ground cover doubled, bare soil decreased, but runoff remained about the same.

In 1963, after the watersheds were stabilized and calibrated, other treatments were applied. One watershed was ripped with a Jayhawk Ripper and was grazed as usual, another was closed to grazing entirely, while the third was held constant as in the 1958-1962 period. The ripping treatment had interesting effects: there was an immediate loss of 20 percent of the grass cover caused by the treatment, but 2 years later forage had increased to the highest level ever attained since the study began. Furthermore, there was no runoff on this watershed the first year after ripping and only half as much as expected the following year. Complete protection from grazing on the other watershed appeared to cause a decline in forage production but increased litter over 300 percent.

Deep ripping has been an effective treatment on the Rio Puerco watersheds for the retarding of runoff water with a subsequent increase of soil moisture reserves for forage production. However, the rips soon seal over from the effects of rain washing fine soil material into the furrows. Although the soil under the surface remains loose, the amount of water penetration depends on the surface structure and on microrelief. The rips remain effective as long as a depression persists. Thus, they would retain their effectiveness longer if the soil from the furrow were thrown downslope. In addition, the old rips may be given a surface treatment and rehabilitated with little drawbar power.

Squaw carpet, the Sierra Nevada ground-cover plant that appears to have great potential for rehabilitating damaged watersheds, has another property that may either limit or enhance its value depending on watershed objectives.

Together with Jeffrey pine, squaw carpet litter seems to contain hydrophobic substances that cause these cover types to behave as shingled roofs. A large proportion of these sites on the east slope of the Sierra Nevada yield considerable amounts of overland flow without producing excessive soil erosion. Apparently the litter restricts infiltration and creates overland flow, but at the same time it protects the soil surface from erosion. Although these results are preliminary, they have important implications. They indicate that some Sierra Nevada cover types, even when in good condition, may contribute substantially more runoff, without the accompanying evidence of soil erosion, than was suspected. They may aggravate flood peak discharges more than other types that provide equal soil stability. On the other hand, in water-yield areas with considerable reservoir capacity, this litter may be useful in precipitation harvesting programs. Jeffrey pine-squaw carpet sites may provide much more water yield than those with high infiltration rates.

More than 1 year of rest in grazing rotation in the Black Hills of South Dakota is necessary for recovery from soil compaction. Bluegrass range plots are recovering as indicated by increasing soil pore volume, decreasing bulk density, and less overland flow as compared with unprotected plots. But the recovery trend is slow.

c. Strip-mined lands. There is a great surge of interest in the problems of strip mining among conservationists, land managers, and landowners. Forest Service research in the restoration of strip-mined lands has been directed toward developing methods for minimizing damage during mining and for quickly establishing vegetation to reduce runoff and erosion and to restore a pleasing and productive landscape after mining.

Erosion from abandoned coal-haul roads in eastern Kentucky amounted to almost 4 inches of soil per year from the road surface and banks. This is a very heavy contribution to stream sedimentation and seriously affects the water quality of streams flowing from mined watersheds. In terms of quantity, roads built on sandy silt lost 1.7 acre-feet of soil per mile of road each year, while those on clayey silt lost 3.3 acre-feet, almost twice as much. The problem can be alleviated by immediate treatment of coal-haul roads upon abandonment. Proper drainage can be accomplished by the construction of cross channels and dips. Road and bank surfaces can be stabilized by grass cover, with tree planting on the banks to follow as the season permits. If properly bedded down and maintained, these roads could serve as access for fire control and recreational use.

Aluminum and manganese in acid spoils from strip mines in Kentucky and West Virginia appear to be the primary source of toxicity limiting plant growth. Although pH is commonly used to decide what species to plant for strip-mine reclamation, it is likely that salts of these two elements, brought into solution by the acidity, are the toxic factor rather than the acidity itself. In a greenhouse study at Berea, Kentucky, plant growth decreased as extractable concentrations of aluminum and manganese increased. The toxicity of other elements is also being investigated. From these research findings it

may be possible to select plants having less susceptibility to those elements found in the spoils to be revegetated.

The effect of strip mining on streamflow has long been conjectured, but until now it has not been measured. As expected, peak runoff rates from strip-mine terraces in Kentucky are high--a peak of 800 cubic feet per second per square mile was the highest to date--and outslopes yielded slightly lower peaks. A peak of 1700 csm. was recorded from a ridge where the overburden was entirely removed leaving exposed bedrock over most of the area. This was an extreme condition, of course, but flumes have been installed to measure these high runoff amounts and they will be related to discharge from the watersheds on which they occur.

d. Burned watersheds. Fire-induced floods and erosion from steep, unstable watersheds are a serious problem in some parts of the country--particularly in southern California. Records show that flood peaks have increased 68 times and erosion rates increased 28 times following fire. Floods and erosion at greatly accelerated rates not only impair watershed values but also are a threat to downstream population centers. Methods for quickly stabilizing destructively burned watersheds are under development.

Mass soil movements following wildfire and heavy rains on the San Dimas Experimental Forest in southern California occurred only on slopes greater than 80 percent. Furthermore, 84 percent of those soil slips were found on areas that had been converted from brush to grass following the wildfire in 1960. Over 1,000 slips were counted on aerial photos of a 700-acre sample of the Experimental Forest. The photos were taken after extremely heavy rains in November and December 1965, about 5 years after the wildfire. The cover conversion that had taken place in the meantime consisted of seeding to grass and an herbicide spray to kill the native vegetation competing with the grass cover. On the untreated area natural recovery of the deep-rooted native chaparral held the soil in place fairly well. But on the treated area it appears that the roots of the killed chaparral had deteriorated and their stabilizing effect was reduced to the extent that much less soil was held in place. Another possible factor was the uniform rooting depth of the grass; a shear zone at this depth may have contributed to soil slippage. Tentative conclusions drawn from this study are that cover conversion should not be attempted on slopes of 80 percent or greater and that an effort must be made to provide a dense cover of deep-rooted species on these slopes.

Chaparral brush fields on the east slope of the Sierra Nevada may be considered a mixed blessing. They have a plus value as good watershed cover following destructive logging, overgrazing, and wildfire. Chaparral sprouts vigorously after fire and provides soil protection against overland flow and erosion. It is superior to forest in this respect. Furthermore, it enhances the fertility of the granitic and andesitic soils by increasing the nitrogen content, and this is an important factor in the reestablishment of conifer seedlings. On the other hand, it is a commercially worthless crop and it offers competition to the growth of young conifers, especially pine. Fifty

years or more may elapse before complete reforestation of this association occurs naturally. Thus, research continues on the problem of how to convert 1.5 million acres of these lands to productive forests. Meanwhile, pending such a solution, this research into the basic characteristics of chaparral associations increases our confidence in the knowledge that the site quality of these lands is not likely to degenerate further.

4. Soil improvement

There are more than 25 million acres of wetland forests ranging from the bogs of the northern Lake States to the swamps of the southeast Coastal Plains. Most of these lands are headwaters for countless streams, and are recharge areas for ground-water supplies in certain localities, but they support only low-growing heaths or degenerate forests. Although their inherent wetness makes management difficult, wetlands have potential for greater forest production if soil-water relations can be improved. Development of management alternatives which will upgrade productivity yet conserve regional water supplies is dependent upon the improved hydrology of these soils. It is an area where there is a dearth of information.

In most years, about two-thirds of the annual water yield of Lake States bogs occurred prior to June 1. High flows in the spring were associated with high water tables when there was little available storage capacity. Low flows were prevalent during summer and fall, and runoff often ceased during mid-summer dry periods. Stored water was not available to sustain streamflow during these periods, and ground water was not a component of flow on these study bogs. Thus, contrary to popular opinion, natural runoff from bog watersheds is not always well regulated.

Experimental water control in a Lake States bog with partially decomposed peat showed little water movement through the peat. An open ditch had little or no effect on the water table 30 feet away. In this type of organic soil, extremely close spacing of ditches and perhaps interceptor ditches would be needed to effectively lower the bog water table.

Studies to date on the Apalachicola National Forest in northwest Florida demonstrate considerably increased growth in young stands of slash pine 3 to 4 years after installing drainage systems on wet, sandy flatwood soils. The data indicate that productivity may be increased from little (site index 50 or less) or nothing to a site index of 75 feet or more at age 50, with adequate drainage. If drainage is inadequate, however, a series of wet growing seasons can cause mortality of planted slash pine, loss of photosynthetic surface, and a decrease in height growth of older trees. There are 2½ million acres of poorly drained pine land in Florida and southeastern Georgia. Landowners are becoming aware of the opportunities to increase the productivity of these lands, but the necessary research results are still incomplete.

Growth of loblolly pine planted on drained wetland sites near Charleston, South Carolina, was almost two and one-half times as great on clayey soil as

on sandy soil. The ratio was the same for both height growth and diameter growth. On the same plots, diameter growth was twice as great in a wet year as compared with a relatively dry year. Both of these comparisons are reflections of greater water availability, but more water is not a simple cause of increased growth. Wet areas without drainage have an excess of water for good growth, and trees growing on slight elevations in both drained and natural sites always have better growth than individuals on the lower levels. Apparently, frequent aeration is another requirement, so a high but fluctuating water table seems to be the desirable condition. From this research, however, it is evident that most development and future research effort should be applied to the heavier soils.

Chemical soil properties differed strikingly between immediately adjacent stands of pure red alder and pure conifer (Douglas-fir, western hemlock, and Sitka spruce), and mixtures of alder and conifers. All stands grew on the same soil type on the Oregon coast. Organic matter, total nitrogen, and acidity were significantly greater in A horizons under the alder and the mixed stands, while the A horizons under conifer stands averaged three times richer in bases than under the alder stands. Observed effects of alder on acidity and base content disagree with the generally held concept of hardwoods as base conservers. These effects may indicate greater production of acid decomposition products in the organic-and-nitrogen-richer alder soils. Results of this study point up the strong influence of vegetation on soil properties which, in turn, may exert an effect on water quality and retention or degradation of chemicals introduced in the forest environment.

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B. FOREST RECREATION RESEARCH

Problem

How can America's public and private forest lands be managed to provide increasing millions of visitors a pleasant outdoor recreation experience? How can these resources be perpetuated in a healthy attractive condition? How can privately owned recreation enterprises be managed at a profit and help meet more of the burgeoning demand for outdoor recreation? The overriding goal of forest recreation research is to provide information which will guide the management of public and private forest lands for recreation and the enhancement of natural beauty, and help coordinate these requirements with other resource uses.

A wide variety of ecological and socioeconomic problems, often interrelated, are involved. With today's "more-so" society--more people with more education, better health, more disposable income, more leisure, more roads, better transportation, and more opportunity for travel--recreation demands not only continue to increase, they are becoming more varied and complex. Meeting these demands and fitting them to the basic requirements of good resource management will be greatly simplified, more effective, and more efficient when we can better answer such questions as: Who uses the forest for his outdoor recreation enjoyment? What are his interests? What does he do? How long does he stay? What are his impacts on the resource, upon other uses, and upon the local and regional economy? What are the trends in recreation choice? As society changes, what changes are taking place in outdoor recreation in terms of numbers, interests, and impacts? What are the criteria for forest landscape aesthetics? How can the forest land manager obtain better understanding and assistance from the public in the task of resource husbandry--a public conservation conscience? More specifically, the immediate research tasks are to obtain facts and test alternatives to (1) determine the criteria for profitable income-producing recreation enterprises on privately owned forests and woodlands, and to help identify the places for both the public and private sectors of outdoor recreation; (2) guide the planning, management, and enhancement of America's forest beauty; (3) provide criteria to select, develop, and maintain at low cost new forest recreation sites which will be heavily used; (4) find effective, inexpensive methods for restoring heavily used forest recreation sites; (5) develop ways to obtain more dispersed and less destructive use of wilderness

and other forest areas especially sensitive to deterioration; (6) provide guides to obtain efficient coordination of recreation with other resource uses of the forest; and (7) provide a better factual basis for policy and management of wilderness and multipurpose forest lands through ecological, economic, landscape management, and user studies that lead to compatibly providing, enhancing, and effectively maintaining aesthetic forest landscapes and attractive recreation opportunities.

USDA and Cooperative Programs

An interdisciplinary team of scientists located at six of the eight Forest Experiment Stations is studying problems of forest recreation in three broad categories--income opportunities and economic impacts, forest recreation use and its physical impacts upon the environment, and the design and enhancement of forested landscapes. Each Station is concentrating its effort on selected critical problems, most often national or interregional in scope. Most of the studies are in cooperation with other Federal, State, and educational institutions.

A total of 16 scientific man-years of effort was devoted to forest recreation research by Forest Service scientists in F. Y. 1967.

Program of State Experiment Stations and Schools of Forestry

A total of 13 scientist man-years was devoted to forest recreation research in F. Y. 1967.

Progress--USDA and Cooperative Programs

1. Income opportunities and economic impacts of forest recreation

Privately owned campgrounds--managerial and physical variables significantly influence their use. Private enterprise now provides the majority of camping in the 14 Northeastern States. There are more than a thousand commercial campgrounds from Ohio to Maine. The ratio of private campgrounds to public campgrounds is 3 to 1 for the region as a whole, and goes as high as 7 to 1 in Maine.

A related study in New Hampshire showed that recreation visit lengths, frequencies of visits, and return visit intentions were all significantly influenced by major attributes of the campgrounds, the campground managers, and the campers themselves. Campground age, geographic location, number of family units, size of investment, and presence of

water were all significantly important. Shorter and less frequent visits were found to occur at campgrounds that were small, new, had low investments, and had no water for swimming. Furthermore, while many of the operators were themselves outdoor recreation enthusiasts, being a camper is hardly an endorsement for prospective campground ownership. Significant reductions in visit lengths, frequencies, and return intentions were evident at the camper-owned enterprises. Perhaps many campers go into this business with the idea that they will fill the need for a "camper's campground," failing to realize that camping means many things to many people and their needs are diverse. The noncamper, on the other hand, not influenced by sentimental bias, may view the problem of campground design from a business standpoint and try to capitalize on these differences.

The ski market is big business and business is good--and good for rural communities. A study of the ski industry and skiing conducted in cooperation with the Department of Commerce in the 12 Western States showed that skier visits totaled 1.4 million in 1955, 4.3 million in 1964, and 12.1 million are expected by 1976. About 95 percent of the skiers were residents of the Western States. The 4.3 million skiers spent $115 million in 1964, and the market potential is virtually untapped. This group makes up only slightly more than 1 percent of the Western population. Male skiers outnumbered females 2 to 1; two-thirds of the skiers were 30 or younger; average daily expenditure per skier was $21; skiers averaged more than 10 days of skiing per year; median annual family income of skiers was $9,500--$2,000 higher than that of the Western population at large. Use was not evenly distributed. The large, highly developed cable lift operations were the most popular. Of the nearly 200 ski areas, 18 percent had 59 percent of the business.

Skiing is an important economic consideration in many communities. More than 15,000 man-days per week were required for operating lifts and tows, for slope maintenance, and for managerial and clerical work. Wages totaled $6 million, an average of $31 thousand per ski area, and $88 million of the $115 million spent by skiers was spent while on the skiing trip. Lift and tow capacities required to meet the estimated increase by 1976 will need to be increased 2 1/2 times. With the exception of California, all of the Western States appear to have an adequate supply of potentially developable new areas for skiing.

Privately owned pulp and paper company lands are an important part of forest recreation in the South. Surveys were made of recreation use on southern pulp and paper company lands--a large and important segment

of the private sector. Eighty-six percent of the industry (38 companies) permit public access to some or all of their lands for recreational purposes. Hunting is the principal activity. Thirteen companies leased a portion of their holdings to hunt clubs. All but two allowed fishing, picnicking, camping, boating, and hiking. Fifteen companies provided special facilities, such as boat-launching ramps, picnic grounds, campgrounds, and fishing access areas. Hunting without permission is permitted on the lands of 24 companies; 8 issue a free permit, and 6 charge a fee. Annual fees range from $1 to $10. Nine companies encourage hunting by distributing brochures, advertising in mass media, and erecting explanatory signs on their property.

A related study made in Brunswick County, Virginia, shows that a large segment of the county's male population are hunters and they hunt a great deal. One-fourth of the county's male residents hunted on pulp and paper company lands, and each hunted an average of 14 days per year. Company policies vary as to fees and use and these facts are not well known. Sixty-five percent of all residents and 50 percent of the hunters knew nothing about the hunting policies of the 4 companies involved. Among the hunters who had some knowledge of the company hunting policies, there was an overwhelming approval of the written permit system. This suggests there is an excellent opportunity for the companies to develop information and education programs which will further improve public relations and leave fewer residents misinformed or uninformed.

Toward fitting camper preferences and campground costs to planning and management. An economic study of 21 National Forest campgrounds in Colorado showed that: (1) Large campgrounds tend to be less expensive (per family unit) to maintain and operate than small ones. Large campgrounds, however, are not necessarily less expensive (per family unit) to build than small ones. Other factors, such as distance and topography, affect construction costs more than does the number of family units per campground. (2) The trend to "sleep off the ground" was reflected in the fact that 41 percent of all campers sampled used trailers, 17 percent used pickup campers, and 38 percent used tents; those using tents and pickup campers used near-highway and back-country sites about equally, but families with trailers used near-highway campgrounds about twice as much as those back off the highways. (3) Neither campground size (total number of family units) nor amount of money spent per family unit to build the campground seemed to influence the amount of its use.

2. Forest recreation use and its physical impacts upon the forest environment

Trends in recreation use of Minnesota's Boundary Waters Canoe Area emphasize more wilderness interest. There have been few chances to study trends in recreational use patterns, but BWCA data for 1961 and 1966 offered this opportunity. All types of visits to the canoe country (paddle canoeists, motor canoeists, boat campers, auto campers, resort guests, day-users) increased 19 percent, but visits to the wilderness core area by paddle canoeists who used isolated primitive campsites increased 52 percent. In contrast, there was a decline of 19 percent in the number of visitors who stay on the edges of the BWCA and go in and out daily for the more general sorts of recreation that are not unique to wilderness. In 1961, visitors traveling by canoe barely outnumbered those using boats; in 1966, over two-thirds of the visitors canoed; paddlers alone made up half of all use; boaters accounted for only 22 percent of the use. The proportion of visitors using the area as a corridor to Canada dropped substantially (47 percent in 1961 to 12 percent in 1966), and Canadian park statistics support this observation.

Water-meters can be an effective tool in estimating recreation use. Recreation management is improved with accurate measures of recreation use. Pneumatic-tube traffic counters have been adequate for estimating use at many sites, but on others they have been a source of trouble. A study on National Forests in Michigan and Arizona shows that water consumption on developed recreation sites is highly correlated with recreation use. Water meters, though more costly, have the following advantages over pneumatic traffic counters as indicators of recreation use: (1) They are less subject to vandalism; (2) they require little maintenance; (3) they are not affected by snow and ice; (4) they provide supplemental information relating use to water and sewage treatment plant requirements.

A net count method of measuring recreation visitor use provides increased accuracy with less labor. A pneumatic traffic counter that separates counts for inbound and outbound traffic was used in a study of recreation use in Utah. The accuracy of a system using two-way counters over a system using nondirectional counters was greatly improved. The difference between the two counts indicates how many vehicles are present at any moment, and this information can be related to the number of visitors present, their activities, and peaks in use. Compared with nondirectional counters, the improved accuracy of the net count method

is achieved with 80 percent less labor. For large sites, the labor saved during the first season in calibrating counts with use will more than offset the additional cost of equipment.

Tree failure accidents on recreation sites. From 1959 to early 1966, tree failures caused an average of more than two injuries or deaths per year on forest recreation sites in California. Pines and true firs were involved in 6 of every 10 incidents involving property damage, and in 9 of every 10 failures resulting in death or injury. This is not an indictment of pines and true firs. These species are most abundant. It does, however, point up the need for research to concentrate on pines and true firs and provide the manager those criteria which will identify hazardous trees. Further research is underway, and some of these characteristics are now known.

3. Design and enhancement of forested landscapes

The need to skillfully establish scenic categories for forested mountain landscapes and to test land management consequences is clearly emphasized in a California study. Traditionally, design concepts have been applied mainly in small scale situations, such as campgrounds and individual or groups of buildings. Forest development, however, is taking place on a massive scale and design concepts must help in preserving the general integrity of forests and ranges and making them pleasant, meaningful environments. And, today, with more and more tourists with their cars on the highway, the view from the road and the "picture" it presents is becoming critically important. A case study in the Sierra Nevada mountains showed that a highway traveler could see more than 57,000 acres along 16 miles of road--an average of 3,600 acres per mile. About 5 percent of the area was classified as critical from a scenic standpoint. Another 50 percent, though somewhat less critical, was still considered to be highly sensitive from a visual standpoint, emphasizing that criteria for scenic categories should be established and that boundaries for such categories must be delineated skillfully.

The design and location of a road can serve to direct attention to valued attributes of the landscape. It can also highlight or focus attention on good--or poor--management practices. By using 3-dimensional, table size, scale models, alternative road and forest management layouts over the entire period of a forest rotation can be tested. A next step would be to establish pilot plant demonstration areas--large enough to represent a broad range of management situations yet small enough to permit intensive planning, a concentration of research effort, and the opportunity to fully and rapidly apply management measures.

PUBLICATIONS -- USDA AND COOPERATIVE PROGRAMS

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C. RANGE MANAGEMENT

Problem

Forage production on extensive areas of rangeland is far below potential and fails to meet the needs for livestock and game. In many areas, particularly in the western mountains, watershed values have been seriously impaired by severe grazing. Management of these lands is often complicated by variable and droughty climate, highly erodible soils, and sensitive vegetation that cannot withstand close use. Furthermore, livestock grazing must be coordinated with wildlife use and often with timber production. Improved management practices must be developed to allow sustained forage production in harmony with other uses and values.

Special phases of the range management problem are: (1) to determine growth characteristics and requirements of range vegetation, (2) to evaluate forage, classify range condition and trend, and develop better vegetation measurement techniques and range inventory procedures, (3) to develop optimum management systems to obtain maximum production and efficient use of forage on the various types of rangeland, (4) to determine effects of fire on vegetation and soils and to develop practical guides for its use in controlling undesirable plants and in increasing quantity and quality of forage production, and (5) to ascertain the ecological relations of rodents and other range pests as a basis for their control.

USDA and Cooperative Programs

This is a continuing, long-term program of both basic and applied research on numerous range plant communities at various locations in the West, Midwest, and South in cooperation with State colleges, universities, and agricultural experiment stations; with the Smithsonian Institution, Bureau of Land Management, Bureau of Indian Affairs, Fish and Wildlife Service, Agricultural Research Service, numerous herbaria, private companies, and livestock associations or individual ranchers. In addition, two PL-480 projects have been underway: germination of seeds of desert plants (Israel) and studies of botany, ecology, and biology of the principal species in mountain pastures of semiarid regions (Spain).

The Forest Service effort in this research is 40 scientific man-years.

Program of State Experiment Stations and Schools of Forestry

A total of 13 scientist man-years is devoted to this area of research.

Progress--USDA and Cooperative Programs

1. Characteristics and requirements of range plants

a. Ecology and physiology. Development and application of effective grazing management practices are contingent upon sound, fundamental information involving all facets of plant growth and the various physical and biotic factors of the environment. Most of these studies are problem-oriented but others are directed towards the underlying facts that define the many range ecosystems and their operational mechanisms. Immediate utility of such research may not be readily apparent but past experience has shown that it yields the necessary broad base for eventual attack on practical problems.

Pinyon-juniper litter was the major factor associated with low production of blue grama (Bouteloua gracilis) on southwestern ranges. Except for this effect, tree cover either did not influence blue grama, or perhaps was even beneficial. Because of the effect of litter, a delayed increase of blue grama should be expected following pinyon-juniper control. Other grass species, particularly those which are deeper rooted than blue grama or which grow at a different season, may have a different relationship with tree cover, roots, and litter.

Bur buttercup (Ranunculus testiculatus) is an introduced annual that is finding a place alongside such well-known introduced annuals as cheatgrass, (Bromus tectorum), halogeton, (Halogeton glomeratus), and Russian thistle, (Salsola kali), in the sagebrush-grass type of Utah and adjacent areas. It has taken over some areas that formerly supported cheatgrass and it has been found growing in the spring on the same areas which supported halogeton in summer and fall. Apparently, it has a wide tolerance range of environmental conditions, being found on both salt-affected and salt-free environments. There are indications that it has an inhibitory effect upon the germination of some grass seeds. It develops early in spring and matures in early summer. It is readily eaten by sheep in the early spring, but it provides little forage because of its low stature and short period of palatability.

Seeds of fourwing saltbush (Atriplex canescens) from six sites in New Mexico were germinated in mannitol solution under 0.3, 3, 7, 11 and 15 atmospheres of osmotic pressure at 49°, 63°, and 85° F. The seeds germinated better at 63° and 49° than at 85° F. However, germination was delayed especially at 49° F. as moisture stress increased. Seeds germinated well even under the relatively high 7-atmosphere levels at 63° F., which suggests that moisture stress may have less effect on seed germination when temperatures are near optimum. Total emergence and rate of emergence were higher, from shallow depths of seeding in sandy loam and clay loam soils. Seeding depths of 1/2 to 1 inch are suggested for de-winged seeds. Since the germination-initial establishment stage is so precarious, chances of successful revegetation of Southwestern ranges are improved with knowledge of the requirements of this high-value forage species.

Relatively low seed fill apparently is a characteristic of fourwing saltbush. Only slightly more than half of 16,000 seeds, representing 117 collections, contained embryos. Seeds from certain sources were consistently better filled than others. The larger seeds within a given collection were usually better filled than the smaller seeds. Cutting tests are recommended so that seeding rates in range revegetation projects can be adjusted to compensate for empty seeds.

Seeds of important grasses, forbs, and shrubs from subalpine areas on the Aquarius Plateau in southern Utah (elevation 9,600 to 11,000 feet) and from aspen and grass-forb types in the mountains of northern Utah and southern Montana (elevation 6,000 to 9,600 feet) were tested to determine conditions necessary to obtain high germination percentages. Alternating temperatures under 8-hour photoperiods, low-temperature stratification, and imbibition in gibberellic acid were the most effective treatments, but combinations of treatments often gave higher germination percentages than any individual treatment. Scarification, leaching, and removal of accessory parts generally increased germination. These studies provide a basis for further physiological research into the role of seed dormancy and the ecology and life history of particular species.

Burroweed (Haplopappus tenuisectus) has replaced choice perennial grasses over about 1 million acres on southern Arizona ranges. The productivity of these ranges could be greatly increased by replacing the burroweed, which is also poisonous to cattle, with cool-season forage grasses or browse such as fourwing saltbush. Results from the Santa Rita Experimental Range show that burroweed uses about 1 inch of soil moisture in February and March which the associated grasses cannot use because they require relatively high temperatures for rapid growth. It is estimated that this same moisture could produce 100 pounds or more of good forage per acre; about a 50-percent increase over the present average production.

Red elderberry (Sambucus racemosa) is an important fall browse species on aspen and subalpine ranges in Utah. It is a rhizomatous species which produces a large number of aerial stems covering fairly extensive areas. These are interdependent and require consideration as one unit in investigations such as water utilization, and transfer of nutrients, herbicides, and pathogens. Acid fuchsin and eosin dyes injected into aerial stems or rhizomes were not effective for determining clone size because of limited translocation and difficulty in detecting the small amount of dye uptake in the foliage. In a successful injection, a 1-percent solution of sodium arsenite, introduced through a severed rhizome, was translocated through the rhizome and caused death of foliage on 68 aerial stems extending over a 3x3 meter area.

Physiological studies are being made in California of native range grasses to determine the most likely plant parts to sample for an efficient evaluation of nutrient status. Nitrogen determinations of Idaho fescue (Festuca idahoensis) showed: 1) Fascicles of Idaho fescue can be used to adequately diagnose the nitrogen status of this plant through the late vegetative growth stage, 2) Top growth was affected more than root growth by low nitrogen, and 3) Nitrate-N in the fascicles should not be allowed to fall below 500 ppm, if maximum growth is desired.

Why damage, either from wildfires or prescribed burns, varies among range forage species is often related to growth characteristics of the plants. In sagebrush-grass vegetation in northeastern Oregon a wildfire resulted in smaller plants and greater actual death losses of Idaho fescue than bluebunch wheatgrass (Agropyron spicatum). Idaho fescue is characterized by a compact crown and buds at or above the soil surface. On the other hand, bluebunch wheatgrass has short rhizomes with buds beneath the surface and a more open crown which tend to lessen the heat intensity. Grazing by cattle before the wildfire occurred apparently reduced the damage sustained by each species by removing a portion of the heat-producing foliage.

Seasonal and diurnal fluctuations in moisture content of twigs and leaves of pinyon (Pinus edulis) and one-seed, Utah, and alligator junipers (Juniperus monosperma, J. osteosperma, J. deppeana) were determined. During the summer in the Southwest, junipers dried during the day in a moisture pattern which was inverse to air temperature. During the winter, junipers became more moist during the day. In general, pinyon did not show the regular diurnal patterns of the junipers. Seasonal fluctuations of moisture content were not well correlated with temperature, vapor-pressure deficit, soil moisture, or precipitation. All species had minimum moisture content in June and November, and peak moisture in July or August. This research is already proving valuable in designing methods of tree control by burning and in shedding some light on the hydrology of the pinyon-juniper type as it is related to moisture losses from the soil.

Because of its high nutritional value, bud sagebrush (Artemisia spinescens) is among the most prized forage plants on sheep winter ranges of the Intermountain region. Bud sagebrush drops its leaves and becomes dormant in June or July after its flush of spring growth. Later, if summer rains wet the soil in the root zone--4 to 15 inches below the surface--some root growth takes place. The harsh, dry twigs may soften with these rains and if the twigs are still soft when winter starts, they are browsed by sheep throughout the winter grazing season. The vegetative twigs are browsed, which in turn stimulates additional vegetative growth. Reproductive branches (inflorescences) arise only from the previous season's vegetative twigs. Thus, grazing reduces flower and seed production and must be regulated to insure adequate numbers of new plants.

Factors regulating germination of annual legumes of desert ranges have been isolated under the PL-480 Project in Israel and offer insight of plant survival mechanisms in a severe environment. Tests on 21 hard-seeded species showed that most are inhibited in germination by water-impermeable seed coats. In some the agent which modifies seed coat permeability is not known while in others high humidity increases seed coat permeability. The degree of swelling of the internal seed colloids determines the degree to which the seed coat, or parts of it, are stretched, thus controlling the degree of water passage into the seed. There is a gradient in each pod with respect to the time required before the seed coat of each seed becomes permeable. Further, the environment to which the mother plant is exposed possibly during the phase of seed formation and maturation may profoundly affect the degree of seed coat impermeability at time of seed dispersal.

Grouse whortleberry (Vaccinium scoparium), a poor forage species, contributes most to the increase in shrub cover following clearcutting of lodgepole pine in Montana; however, other species provide a potentially important forage resource for livestock and big game for an estimated 20 years while a new timber stand develops. No significant difference was detected in ground cover on the different "seedbeds" created by burning and scarification of the soil; however,forb production tended to increase and shrub production decreased. In general vegetation yields on the clearcut areas were closely correlated with percent ground cover. Therefore, ground cover measurements which are more easily made should provide reliable estimates of production.

Aimed at evaluating potential productivity of range sites an ecological reconnaissance in the Thurber fescue (Festuca thurberi) grasslands of the southern Rocky Mountains, a promising classification of 5 site types has been developed on the basis of soil parent materials: (1) Glacial drift soils of mixed granite, tuff and other volcanics; (2) Residual sandstone soils; (3) Rhyolitic soils; (4) Basaltic soils; (5) Soils from Maroon Conglomerate. Thurber fescue and other characteristic species were associated with each of the soils. Generally, the communities occur from elevations of about 8,500 ft. to 11,500 ft. on dark well drained soils with high moisture holding capacities.

b. Taxonomy. A continuing effort is required in plant taxonomy to provide reliable identification of the complex floras of the many range plant communities. The kinds of understory plants largely determine the capacity of forest and related ranges to produce livestock and wildlife.

A recent publication describes more than 80 plants--grasses, grasslikes, forbs, shrubs, and woody vines--that commonly inhabit longleaf pine-bluestem ranges. Each species is described in non-technical terms to assist users having little or no training in taxonomy. For botanists, detailed technical descriptions are provided. Line drawings show salient taxonomic features. Both descriptive and illustrative materials stress vegetative

characters to aid identification when floral parts are absent. Finally, each species is assessed as to forage value for cattle and wildlife and its geographic range is defined. The publication will be especially valuable to resource managers in analyzing forage resources.

Monographs of 75 species (46 leguminous and 29 gramineous) native to the semiarid, mountainous regions of Spain have been prepared under a PL-480 project. For each species there is presented the taxonomic description, vegetative characteristics, ecology, forage value and possible adaptability to other sites throughout the world.

A range plant code provided by Forest Service research facilitates recording of plant names and their adaptation to programming for electronic computer analyses. Construction and acceptance of a standardized computer code for forest and range plants has not only provided financial savings, but to date it has also made possible the pooling and coordination of vegetation research among the range management departments of three universities in the Northwest.

Keys, habitat notes and distribution of sedges in Wyoming have been published as a complementary effort to the forthcoming text of a Manual of Sedges of the Rocky Mountains. A similar treatment of the family Juncaceae in Wyoming included the 2 genera and 28 species of the family which are known in that State. In addition, 5100 plant specimens were identified or verified for field personnel and others by the Forest Service Herbarium; approximately 2800 specimens were permanently mounted as permanent vouchers.

2. Range vegetation evaluation

a. Forage value. Since livestock welfare and performance are closely related to palatability and nutritive value of the forage, efforts are being made to determine quality of various kinds of forage plants by chemical analysis, in vivo and in vitro digestion studies and by practical grazing management trials. Evaluation of the production efficiency of various key forage species is an essential component of intensified grazing management.

Stored carbohydrates is a matter of adequate food being manufactured by the plant. The natural cycles of these food accumulations in key forage species are a good physiological basis for establishing proper season of use and grazing system. Elk sedge is a key forage species on mountain summer rangelands in the Northwest and during April, May and much of June the carbohydrate level is only about one-half what it is when its summer growth has been completed. Hence, elk sedge would be adversely affected by grazing before this time.

On these ranges there were almost no differences in carbohydrate accumulations of key forage species subjected to light and moderate grazing. Under heavy grazing, carbohydrate accumulation was definitely less. There was also a

tendency for greater carbohydrate accumulation under deferred-rotation than under seasonlong grazing.

Information which can guide management on thousands of acres of spring-fall range in eastern Oregon shows grasses have a high crude protein level in the spring and low in the fall; it characteristically becomes deficient for range livestock (less than 8.3 percent crude protein) during July. In general, shrubs maintained crude protein levels above 8 percent throughout the season; big sagebrush showed the most desirable chemical composition during the winter. Bitterbrush, (Purshia tridentata), was lowest in phosphorus, apparent digestibility and crude fat, and highest in crude fiber of the four shrub species sampled during the winter. Forbs provided more phosphorus than grasses or shrubs.

Cattle receiving daily 0.34 kg. of protein supplement fortified with trace mineral salt and dicalcium phosphate finished the spring-summer-fall grazing season 50 pounds heavier than unsupplemented animals on dry crested wheatgrasses in the Intermountain region. The animals consumed sufficient supplement plus a free choice mineral mix containing dicalcium phosphate to approximate the minimum daily phosphorus requirement throughout the season. Animals receiving no supplement were also offered the mineral mix free-choice but their consumption was no greater than the animals receiving supplement. Thus, they received considerably less phosphorus than the minimum daily requirement. Free-choice consumption of dicalcium phosphate declined slightly from late summer into late fall as the phosphorus content of the forage declined. Since this could be related to the low palatability of the dicalcium phosphate salt, a more palatable source of phosphorus should be developed. This knowledge of phosphorus consumption and needs of cattle while on these ranges is important for ranchers who seek maximum weight gains on their cattle.

Analyses of forage from the rumen of fistulated animals showed that cattle were on a higher level of nutrition where a combination of seeded ranges was incorporated in a yearlong grazing system with native ponderosa pine-bunchgrass range in Colorado. Crude protein and phosphorus in the diet of a cow herd grazing such integrated ranges were more than adequate for 10 months of the year, whereas, these nutrients met requirement levels only 8 months on native range. The higher plane of nutrition increased calf weaning weights 32 pounds per head. The seeded ranges provided these advantages because they started growth earlier in the spring and remained green later in the fall. The search for better forage grasses to extend the green growth period offers promise of increased animal production and should be intensified.

Cattle of the Ozark region used old fields and open glades in late spring, feeding mainly on forbs; in early summer their feeding was mainly in woods on browse and mushrooms; old fields and open glades furnished grazing in mid and late summer when they fed mainly on grasses and sedges; and during fall months they grazed brushy glades and open woods, feeding on fallen

fruits and grass. With this knowledge, the cattle owner can locate calf creep feeders and supplemental feeding stations in accordance to cattle pattern of use. A phosphorus supplement after late June is suggested to increase beef production on these wooded grasslands.

b. Vegetation measurement and sampling. Progress in range research and management has been impeded by difficulties in obtaining quantitative measurements of vegetation, particularly herbage production. Methods are being sought that combine accuracy, rapidity and simplicity, together with techniques to improve sampling efficiency and development of experimental designs appropriate for range studies.

Three techniques to determine forage utilization by livestock on southern forest ranges were compared in a Louisiana study. On moderately grazed range, the stationary-cage method appears best. In this method one quadrat was protected by cages throughout the grazing season; three adjacent quadrats were grazed. In the fall all were clipped. Utilization was determined by the herbage-weight difference between the caged quadrat and the average of the grazed. It is as accurate as the other methods, and it requires less field work and computation. Excessive field time discourages general use of the other two techniques, the transient-cage and plucked-quadrat.

Food intake of livestock is generally very difficult and expensive to measure. Water-intake rates of free-grazing cattle on shortgrass range in Colorado were used to develop a method of estimating the amount of food eaten. The method requires the measurement of mean air temperature, moisture content of forage, and water drunk. The mean adjusted food intake of yearling Hereford steers was 17.6 and 18.2 lb. per day, as estimated by water-intake and herbage-clipping methods, respectively.

On the Santa Rita Experimental Range, Arizona, the microscope-point method with rumen-fistulated steers was valuable for determining seasonal changes in the kind and amount of forage taken by cattle. The average percentage of species that made up 25 percent or more of the rumen contents could be estimated to within 10 percent at the 90-percent level of probability with 400-point observations. Accurate estimate for species that made up less than 5 percent of the diet required more than 400 points. It was learned not only that the diet changes seasonally but also the rumen contents are not always closely related to the abundance of the forage species on the range.

A comprehensive bibliography of 1,118 references, most with abstracts, has been prepared for use by researchers, educators, and administrators. It is divided into three parts--plant measurement, animal measurement, and statistical theory and method. References are cross indexed, and an author index is given to increase its utility. The annotated publication entitled "An abstract bibliography of statistical methods in grassland research" has been issued as U.S.D.A. Miscellenaous Publication 1030.

Forage yields and stocking rates on crested wheatgrass ranges in the Front Range of Colorado can be predicted from precipitation measurements. Specific precipitation patterns accounted for 87 percent or more of the variation in forage yields of ranges grazed at different seasons. April rainfall determined available forage on spring ranges and May-July moisture on fall ranges. The method of analysis used in evaluating the precipitation-production relationships should be useful for determining similar relationships on other western rangelands and should overcome the major problem of advance estimation of the number of animals to graze on a range with large annual fluctuations in forage production.

c. Condition and trend. Good range management requires fundamental information about the range ecosystems, including sound methods for determining condition in relation to potential and for recognizing and evaluating changes resulting from grazing use. To permit early applications of corrective management, sensitive indicators of trend in range condition are necessary.

The difference in forage production is about 50 percent between excellent and good condition ranges in the northern Great Plains with smaller differences between good and fair condition ranges. Basal cover did not show large differences between most ranges in excellent, good, and fair condition. However, average leaf heights of the mid-grasses were usually substantially higher on ranges in excellent condition. Only a small reduction occurred on fair ranges compared to good ranges. This information is applicable to 50 million acres of mid-short grass range in North Dakota, South Dakota, and Montana.

On a salt-desert shrub range in western Colorado, Salina wildrye (Elymus salinus), a native bunchgrass, was more palatable to sheep and cattle than any other species. Over an 8-year period, winter use of wildrye averaged 76 percent as compared to 50 percent for Indian ricegrass (Oryzopsis hymenoides), the next highest species. Salina wildrye also effectively retards soil erosion on heavy-textured, saline soils. These features, and its ability to withstand close grazing under arid conditions, suggest its use for providing much more forage and improved watershed cover on several million acres of western rangeland.

3. Livestock grazing practices

a. Native ranges. Although studies of ecology, physiology, taxonomy, forage value, and vegetation measurement are basic to the development of range management practices, actual grazing trials are necessary to determine the true worth of such practices. Also, it should be recognized that results of such trials cannot be widely extrapolated; consequently, separate grazing studies must be conducted for a wide range of native plant communities and environmental conditions.

In Louisiana requisites for management in longleaf-slash pine forests are being developed. These include feeding supplements to compensate for deficiencies in range forage; using Brahman-cross cows; improving forage quantity and quality through controlling tree density and prescribed burning; grazing at proper intensity; and regulating cattle distribution, numbers, and season of grazing. When properly managed, calf crops exceed 75 percent, weaning weights of calves are more than 400 pounds, and production of timber is unimpaired. Annual profits from beef may reach $28.00 per cow, an annual return of 10 percent. This is in contrast to usual marginal operations on southern forest rangelands.

On grasslands in the Big Horn Mountains, Wyoming, weight gains of steers were highest with a deferred-rotation system of grazing wherein utilization of Idaho fescue averaged 20 percent. Seasonlong use of a similar range stocked comparably was next best, but a third range stocked one and one-half times as heavy and grazed on the same deferred-rotation system produced the lowest daily gains. Weight gains averaged 2.21, 2.01 and 1.88 pounds per day, respectively. Deterioration occurred on the range grazed under the heavy-rotation system but not under the other two systems.

Equipment that will weigh range cattle without disturbing them has been developed at the Santa Rita Experimental Range in cooperation with the University of Arizona. The system consists of a simple, inexpensive platform supported by four load cells (transducers) connected to a battery-operated chart recorder. The platforms are placed where cattle cross them daily going to water. The load cells respond to weight without change in the appearance or "feel" of the platform. The transducers can be moved easily from one platform to another. With these scales scientists can easily weigh cattle as frequently as necessary without affecting the animal's rate of gain in a particular treatment.

Under light and moderate stocking (10 and 7.5 acres per cow-calf month) production of forage was increased or maintained on intermingled grassland and timbered ranges in the mountainous portion of the Northwest. However, on timbered ranges only the light rate maintained the more valuable forage species. Little difference in production of principal grasses was found between deferred-rotation and seasonlong grazing systems. Heavy grazing (5 acres per cow-calf month) resulted in more bare soil and less litter. The deferred-rotation system furnished better ground cover for watershed protection than did seasonlong grazing system. Cattle weight gains were inversely related to intensities of cattle stocking, but no relationship was found for systems of grazing. These leads are useful guides of what land administrators and ranchers might anticipate in intensified management of similar ranges.

Yearling cattle on cheatgrass forage in southern Idaho make satisfactory gains over a 7-month grazing season (April-October). However, native and introduced perennial grass ranges are likely to produce more beef per acre

than cheatgrass ranges and management that furthers conversion appears desirable. At Saylor Creek Experimental Range livestock production reached 18.2 pounds per acre when pastures were stocked at the heavy rate (17.2 animal days per acre). In the spring, gains per acre were highest at 20.6 animal days per acre but, during the summer and fall, they declined when use exceeded about 60 percent of the available herbage. Daily gains decreased with an increase in stocking rate. However, during the early and late spring seasons, daily gains were greatest at the moderate rate of grazing, but they were greatest at the lightest rate during the summer and fall.

Periodic clipping to simulate grazing in the southwestern Ozarks of Missouri shows maximum yields of native bluestem ranges cannot be sustained by grazing every year in mid-summer. Clipping after floral initiation, but before anthesis, over a three-year period caused up to 60 percent reduction in yields. Clipping during other times of the growth period caused a 40 to 50 percent reduction in yields. These results, therefore, suggest fall and winter grazing. However, grazing these grasses in fall and winter is not when they are most palatable and nutritious. Therefore, a grazing management system of rotating summer rest periods with summer, fall, and winter grazing use is suggested.

Rest-rotation management on the Harvey Valley allotment in northern California produced better range conditions than neighboring allotments grazed seasonlong. Vigor of the key forage species, Idaho fescue, was decidedly better and measurements of desirable plant cover, species composition, grass seedlings, herbage yield, and soil surface factors favored rest-rotation. Yearling heifers made nearly twice as much gain in 1966, under rest-rotation as under seasonlong grazing. In only 4 of 14 years did cattle grazing in one unit all season make better gains than cattle grazing in two or more units.

From the reaction of longleaf pine-bluestem range in Louisiana moderate stocking stimulated production as much as heavy grazing, without the drastic changes in vegetation. Also, it was less damaging than heavy use to pine regeneration and soil conditions. Grass production averaged more than 3200 pounds (airdry) per acre annually under both intensities or about 800 pounds more than the ungrazed range. Burning at 4- or 5-year intervals had no effect on grass production. Grass cover declined under grazing, but decreased even more on ungrazed range, largely because of loss of slender bluestem, (Andropogon tener). A. divergens increased on ungrazed range, decreased on heavily grazed range and remained about constant under moderate use. Common carpetgrass (Axonopus affinis) increased greatly on heavily grazed range.

A large part of the diet of animals grazing native chaparral pastures at Tonto Springs in Arizona apparently comes from browse, although exact amounts are unknown due to the difficulty of measurement. Grass and forb consumption per animal day (pounds-ovendry) for seeded range is about twice

that for native chaparral range. Weight gains were similar for animals on both types of pasture. Therefore, about 1/2 the energy necessary for growth and gain must be attributed to browse. The 4 million acres of southwestern chaparral may have values for grazing that were previously unsuspected.

Marking experimental animals at Manitou Experimental Forest, Colorado, for easy and accurate identification in the field has been difficult in the past. A human hair dye, Miss Clairol, was found effective for temporarily marking experimental livestock. Large, easily applied numbers could be read at a considerable distance for the life of the hair coat--150 to 180 days when the dye was applied in the fall. This method of marking livestock has particular application for data keeping in breeding and commercial livestock improvement programs as well as in research studies where detailed data are kept on individual animals.

b. Improved ranges. Where ranges have been improved by prescribed burning, seeding, fertilizing, plant control or other cultural practices, the need for subsequent proper management is critical to protect the resource and the investment in the improvement program. Optimum seasons, intensities and systems of grazing must be developed especially for seeded areas throughout the West and for areas where low-value trees and shrubs have been converted to grassland.

Grazing seeded Sherman big bluegrass (Poa ampla) to a 4-inch stubble height, or about 65 percent use of the plant by weight, was found better than grazing to either a 2-inch or 6-inch stubble height. These results were obtained from a 7-year study of grazing big bluegrass at three intensities at the Manitou Experimental Range in central Colorado. Grazing to a 4-inch stubble maintained the grass stand and gave 1.71 pounds per day average gain on yearling heifers.

Some introduced seeded species have proven more productive than native forage plants at Manitou Experimental Range in central Colorado. Beef production from Sherman big bluegrass ranges averaged 78.3 pounds per acre compared with 71.6 pounds on ranges seeded to a mixture of crested wheatgrass, (Agropyron cristatum), smooth brome (Bromus inermis), and yellow sweetclover, (Melilotus officinalis), and 13.5 pounds per acre from moderately grazed ponderosa pine-bunchgrass ranges. With an average price for beef of $25/cwt. big bluegrass produced $1.67 larger gross income per acre than areas seeded to any other introduced grasses and $16.25 larger income per acre than the native bunchgrass ranges.

Crested wheatgrass (Agropyron desertorum) range can be effectively used for lambing in northern New Mexico, thereby furnishing a much needed supply of forage at a critical period. Stands were grazed by sheep during the spring lambing season each year for 3 years. Utilization under four stocking rates averaged 39, 53, 72, and 84 percent by weight. In 3 years production of

the wheatgrass was not affected by intensity of use during the lambing period; however, in heavily grazed stands wheatgrass plants were not being replaced as rapidly by young plants, old plants were smaller, and ground cover was sparse.

Yearlong continuous grazing at a moderate rate on annual-plant ranges in California shows advantages in breeding cow performance over seasonal grazing. Average weight of bred or wet cows was over 100 pounds greater in the yearlong treatments. Similarly, calf weaning weights averaged over 50 pounds heavier on yearlong treatments.

4. Burning and other range improvement practices

Ranges are often so deteriorated by overgrazing or other disturbance factors that good grazing management alone cannot be expected to restore them within a reasonable period of time. To prevent further loss and speed recovery various drastic improvement measures are frequently justified. The present vegetation is often manipulated by such practices as burning, spraying with herbicides or applying mechanical measures. Seeding of desirable forage species is often done as part of the range improvement effort.

Grass production can be increased up to 100 times on some sites in Missouri. Aerial spraying wooded pastures with 2,4,5-T in early June, prescribed burning in August, fertilizing immediately after burning, seeding K-31 fescue in early September or native grasses in late February were all important for efficiently and successfully establishing good forage. After grasses became established, these sites produced an average of 3,000 pounds per acre. A cow year requires approximately 6 acres of this grassland. Upper south and west slopes were best suited to native grasses such as Indiangrass (Sorghastrum nutans) or switchgrass (Panicum virgatum). On sites with shallow soil or on upper north and east slopes more forage was produced when seeded with fescue. Lower south and west slopes produced approximately equal amounts of fescue or native grasses.

Blue oak (Quercus douglasii) is considered undesirable on California rangeland and its control is a widely recommended and accepted practice to increase herbage production. However, in some areas with shallow soil and annual species, blue oak is an asset rather than a liability and ranchers may well reconsider their plans for its control. Results from thousands of plots on the San Joaquin Experimental Range for the past eight years show that herbage yield under blue oak canopies is consistently higher than out in the open. The advantage varied from 166 to 1059 pounds per acre. In addition, green forage under the canopies was available earlier in the year and used by cattle later than that outside the canopies.

Abundant forage is produced on southern forests, but quality is low except for brief periods following burning. To complicate this problem, the South has 15 million acres of recently planted pines in which burning must be

deferred. Recent research indicates that grazing of pineywoods may be improved by (1) limited site modifications, such as chopping or disking and application of rock phosphate, or (2) intensive culture including introduction of improved forage species into managed plantations. These findings help integrate the growing trees and beef and provide landowners with alternatives for increasing productivity of the land resource.

Sherman big bluegrass is one of the better forage species for seeding ranges in the ponderosa pine zone in Colorado, but successful establishment has been difficult. Establishment was best at the Manitou Experimental Range, Colorado, when seed was planted into a moist seedbed during July and August to a 5/8-inch depth using a double-disc, depth band drill. These findings will permit more widespread use of this desirable species without the past risks of seeding failures.

Fire can effectively reduce a stand of the undesirable burroweed, but reinvasion may be rapid. In Arizona it was found that the benefits to be expected from burning depend largely upon the grazing practices before and after the fire. A controlled burn on the Santa Rita Experimental Range in June 1952 killed 98 percent of the 3,762 burroweed plants per acre. In 1958, after 6 years of below average winter moisture, the burroweed count was 1,078 per acre. With favorable winter moisture, burroweed density reached 7,175 plants per acre by 1965. Reinvasion was more rapid on areas grazed yearlong than on areas protected from grazing.

Herbage on unburned pine-bluestem range is generally deficient in protein after early summer and in phosphorus all year. The widespread practice of burning southern coniferous forests during winter increases these nutrients in new growth, but the benefit is short-lived. However, in Louisiana it was determined that protein in herbage from spring-burned plots was substantially higher in June than from those burned in winter. New growth on summer-burned range provided adequate protein after levels became submarginal on spring-burned plots. In midwinter, protein on previously unharvested summer-burned plots was significantly higher than on plots burned earlier. Reaction of phosphorus content to season of burning was similar to that of protein. Results suggest that the problem of inadequate protein in herbage during summer and fall may be largely resolved by burning parts of a range unit at intervals, from late winter to midsummer. Improvement of herbage quality should be reflected in greater gains by calves and better condition of cows during the breeding season. Also, with cost of high-protein feeds mounting, deferring use of summer-burned range until winter could effect substantial savings in supplemental feeding.

Because juniper trees have reduced the forage production on millions of acres of western rangelands, many ranchers and land management agencies are conducting juniper control programs. In Arizona it was found that burning individual trees is one suitable technique for killing nonsprouting species like Utah juniper. For complete kill, 60 percent of the crown

should be scorched. The time required to achieve enough scorch increased with wind and tree size, but decreased with temperature. For many stands this is the lowest cost control method yet developed.

Grass production on southwestern ranges can be increased by chemical control of half-shrubs, although the response may not be as great as would be desired. Selective phenoxy sprays applied to broom snakeweed (Gutierrezia sarothrae)and Cooper actinea (Hymenoxis cooperi)reduced these half-shrubs from an average of 410 pounds per acre to 77 pounds. As a result, weight of blue grama on the treated plots increased 14 to 38 percent over the untreated check plots. Bottlebrush squirreltail,on the other hand, was not related to the amount of half-shrubs and because of its growth characteristics is apparently not competitive with them. In general the analysis indicated that for each pound of the half-shrubs killed by the spray, less than one-half pound was replaced by herbaceous plants. It is reasonable to assume that if more half-shrubs had been present, responses of herbaceous plants due to treatment would have been greater.

Picloram seriously reduced emergence and growth of fourwing saltbush seedlings on the Santa Rita Experimental Range in Arizona. Picloram was used to control burroweed and creosotebush (Larrea tridentata) before planting the saltbush. Apparently, picloram should not be used to kill other brush where fourwing saltbush is to be planted.

Practical control of velvet mesquite (Prosopis juliflora var. velutina), a problem brush species on Arizona ranges, can be obtained with two aerial sprays of 2,4,5-T a year apart. Tracts of from 40 to 800 acres on the Santa Rita Experimental Range were sprayed at costs of $3 to $5 per acre ($1.50 to $2.50 per spraying). Mesquite is most susceptible, usually late in May when the leaves are full sized but still succulent, the pods are half grown and twig elongation has ceased. Two sprayings usually kill about 60 percent of the trees and about 90 percent of the top wood. Regrowth of surviving mesquites from sprouts is relatively slow. Grass production increases promptly; and under moderate grazing the benefits last for many years. Aerial sprays meet the need of ranchers and public land administrators for an effective, economical, large-scale method for increasing forage production on vast acreages of semidesert range.

Alpine avens (Geum rossii), an ubiquitous and unpalatable alpine species, was easily controlled with herbicides. Cooperative studies with the University of Wyoming showed that 2,4-D and 2,4,5-T were equally effective. Either herbicide, when applied at rates as slow as 1 lb/acre, reduced the density of avens by about 98 percent.

Because of its resprouting and competitive ability, attempts to control lanceleaf rabbitbrush (Chrysothamnus viscidiflorus var. lanceolatus) with 2,4-D have often been unsuccessful. Successful programs require proper timing of spray applications to achieve maximum long-term benefits.

Evaluation of sprays of 2 and 4 pounds of 2,4-D per acre on high-elevation cattle range on the Humboldt National Forest which were applied in late June 1956, reduced the rabbitbrush and forbs, and increased grass production. Rabbitbrush at the time was almost in full leaf and soil moisture was adequate. In contrast, an August spray, when plants and soil were dry followed by a spray in early June 1957, increased rabbitbrush production, reduced forb production and did not change grass production. Where rabbitbrush kill was better, grass production was still 350 pounds per acre greater after 8 years. Thus it appears that the increased grazing obtained from the spraying will be economically beneficial.

5. Range pest influences and control.

Rodents, rabbits, insects and diseases often cause forage losses of considerable magnitude on rangelands. However, the actual effects on grazing values, soil and watershed are not well understood. Neither are the circumstances responsible for buildup of damaging populations of indigenous pests nor the conditions necessary for their control. Identification of pests and understanding their ecological relations are required as a basis for their control.

The white-footed deer mouse, the Great Basin pocket mouse, and the western harvest mouse are relatively common throughout the sagebrush-grass and adjacent pinyon-juniper vegetation types in central Utah. The white-footed deer mouse was most common on heavily grazed areas and areas of dense juniper and where vegetative cover was sparse, whereas the western harvest mouse was most common in areas with dense grass. In addition to the deer mouse and pocket mouse, only the chipmunk was found in the area having dense juniper. On an adjacent area where junipers were invading, all three species of mice were found. Here also were found the Least chipmunk, Northern grasshopper mouse, and vagrant shrew. Knowledge of the habitat relations and food requirements of these and other rodents are contributing to a better understanding of range communities.

Meadow voles (Microtus spp.) are capable of causing severe damage to native shrubs by bark stripping when there is a sudden population irruption. Up to 84 percent of big sagebrush plants were killed on areas several hundred acres in size in three counties in Utah in the winter of 1963-64. Other shrubs were similarly affected, but the damage was not so pronounced. The herbaceous understory was apparently undamaged by the outbreak of voles, and grasses and forbs may benefit by reduction in sagebrush competition.

Insects are estimated to cause several million dollars loss of range forage annually in the Intermountain region but in general the role of specific insects on specific plants is not known. In one summer over 250 different species of insects were collected from four important plant species in the sagebrush-grass type of central Utah. Rubber rabbitbrush (Chrysothamnus nauseosus) supported a greater variety and greater number of insects than

did big sagebrush, bitterbrush, or crested wheatgrass. Gall-forming insects and spittlebugs were particularly abundant on rabbitbrush in 1966, causing great damage. A third type of damage to rubber rabbitbrush resulted from Cicadid nymphs feeding on the roots. In some areas these exceeded 30 nymphs per plant in the 12- to 30-inch depth. Most severe damage to big sagebrush was caused by a sagebrush defoliator (Aroga websteri), gelechid moths (Gelechia spp.) and gall-forming insects. A small seed-eating dipteran was the most abundant insect found on bitterbrush. Foliage of crested and several other introduced wheatgrasses was heavily damaged by the black grass bug (Labops hesperius) and another species of Miridae in some areas of central Utah and southward. Better understanding of insects and their hosts offers exciting possibilities for increasing range forage and prevention of loss of seeded stands.

DDT has been used in many areas to control forest insect epidemics. However, both domestic livestock and big-game animals use the forage plants within forest stands and consequently it is important to determine the amount of spray residue on forage plants. This is dependent of course on the density of the overstory and the rate of insecticide application. Results on one insect control area near Burns, Oregon, showed only 0.30 gallon of spray solution per acre reached the understory plants when a mixture of 1 gallon of Diesel oil and 3/4 pound of DDT per acre was applied per acre over the forest stand. The DDT residues on the forage plants decreased rapidly during the 15-week grazing period and in the following grazing season it was not detected. In range areas where DDT is used, livestock approaching slaughter-age should be withheld from freshly sprayed areas during the summer period in which the spray was applied.

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D. WILDLIFE HABITAT MANAGEMENT

Problem

Wildlife habitat, by supplying food, cover, and water, is the key to optimum game and fish production. Management of habitat is complex. Each species of animal has rather specific habitat requirements that must be balanced with production of water, timber, and forage for livestock. Demands for all uses of forest and related range lands are increasing, and serious situations have arisen, often with severe impacts on game and fish habitats. Consequently, wildlife habitat research is needed to develop effective and harmonious management practices for the various vegetation types.

Specific phases of the problem are: (1) to devise methods for restoration of deteriorated habitats or for improvement of those naturally unproductive; (2) to develop and evaluate management systems through studies of the nature and degree of competition between wildlife and livestock, effects of timber production and cutting practices on forage for wildlife, and reciprocal effects of forage production and grazing use on timber reproduction; and (3) to determine the effects of land use on fish habitat and to develop ways to improve fish habitat and food supplies by such means as regulating shade and water temperatures, manipulating riparian vegetation, and stabilization of streambanks.

USDA and Cooperative Programs

This is a continuing, long-term program of both applied and basic research at numerous locations in the various plant-animal communities throughout the United States. It involves interrelations of wildlife and livestock, and integration of timber and forage values to allow optimum production and utilization of each. Studies are conducted in cooperation with various State and Federal agencies such as fish and game departments, agricultural experiment stations, Fish and Wildlife Service, Soil Conservation Service, Agricultural Research Service, Bureau of Land Management, and in some instances with sportsmen associations, private companies, and individuals. In addition, there is a PL-480 project concerned with quantity, quality, and seasonal variation of food resources available to red deer (Poland).

The scientific effort in this research by the Forest Service is 27 scientific man-years.

Program of State Experiment Stations and Schools of Forestry

A total of 42.6 scientist man-years is devoted to this area of research.

Progress--USDA and Cooperative Programs

1. Wildlife habitat improvement

Improvement of wildlife habitat requires the development and evaluation of such special practices for increasing food and cover as seeding, planting, burning, spraying, and fertilizing. Satisfactory methods of revegetation are particularly needed to restore seriously depleted big-game winter ranges of the West. Improvement measures are also needed for naturally unproductive habitats and for the establishment of desirable streamside vegetation for the production of fish.

More than 100 plant species, which have been tested in Utah, hold particular promise for restoring game ranges in the juniper-pinyon type. The top three shrubs, forbs, and grasses are shown below:

Fourwing saltbush (*Atriplex canescens*)	Alfalfa (*Medicago sativa*)	Crested wheatgrass (*Agropyron cristatum*)
Bitterbrush (*Purshia tridentata*)	Sickle alfalfa (*M. falcata*)	Desert wheatgrass (*A. desertorum*)
Big sagebrush (*Artemisia tridentata*)	Small burnet (*Sanguisorba minor*)	Intermediate wheatgrass (*A. intermedium*)

Because of the wide variation in succulence of the species in different seasons, it appears possible by seeding the proper selected species to extend the period during which game can graze the foothill ranges. Planting appropriate species may also be used to regulate big-game grazing of certain areas. Results universally show that successful restoration of depleted game ranges can be carried out in the face of severe pressure from game; however, it is important that restoration be done on large tracts, preferably in excess of 500 acres.

Findings on a 600-acre tract near Manti, Utah, which supported a closed stand of juniper and pinyon, before chaining and seeding in 1961, are indicative of the improvement that can be made. Before clearing and seeding, the area supported about 400 trees per acre and provided less than 70 pounds of understory herbage per acre. Total ground cover was 38 percent. By the third year after treatment, a nearly full stand of seeded species was producing 1,600 pounds of forage per acre, resulting in a ground cover of 89 percent. While shrubs were producing only a small proportion of the total, substantial increases can be expected because shrubs tend to be considerably slower in development than herbs. Results on more than 80,000 acres of juniper-pinyon range now treated and seeded show tremendous opportunities for increasing the forage resources for game and livestock within this broad vegetation type. In Utah and Nevada alone, there are more than 20 million acres which could be similarly improved.

Selection and hybridization show promise for extending the range of adaptation of several shrubs in the Great Basin, and also for increasing the quality and quantity of the forage they produce. In Utah, seedlings resulting from the artificial pollination of the pistillate shrubs of fourwing saltbush by mat saltbush (Atriplex corrugata), Gardner saltbush (A.gardneri), (A. cuneata), spiny hopsage (Grayia spinosa), spineless hopsage (G.brandegei), and black greasewood (Sarcobatus vermiculatus) appear hardy, and most of them show marked improvements in foliage characteristics over the parents. Several of the hybrids, including the intergeneric crosses, produced good seed. Important progress has also been made in artificially hybridizing various oaks (Quercus spp.) and more limited progress has been made on shrub species within the Chenopodiaceae family.

In general, germination of fourwing saltbush was decidedly higher from bushes having small bladderlike-one seeded fruit or utricles than from bushes having large utricles on the Huntington Game Refuge in Utah. Not only is germination better but there are a great many more small utricles per pound, and more seeds are available for producing shrubs. In addition to better germination, there was a marked tendency for better fill of the small utricles than in the large utricles.

For better stands of two important native forbs on Intermountain game ranges, heavy-intensity sulfuric acid scarification of seeds of gooseberryleaf globemallow (Sphaeralcea grossulariaefolia) and Snake River Plains milkvetch (Astragalus filipes) increased the germination from 8.0 to 81.0 percent and 14 to 65 percent, respectively. While moderate and light acid scarification was helpful, neither was as effective as heavy. Results indicate that acid scarification will be a useful technique in conjunction with other chemical treatments for increasing the seed germination and field establishment of several other forbs and shrubs which have been tardy or difficult to establish from direct seeding.

Moist and dry heat treatments were applied to seeds collected in Georgia and used for game planting in flatwoods pine stands of the Southeast. Seeds of Cassia nictitans were exposed in the laboratory for varying periods and intensities to explore possible mechanisms by which fire may benefit germination through its direct effect on the seeds. Moist heat was much more effective than dry heat in increasing rate and total germination. Upon further study it was learned that water at 80° C. for 4 minutes removed a cuticular substance from the seedcoat. It is surmised that during a fire water vapor should be available from drying subfuels and from combustion itself to remove this inhibitory substance. Such results are providing insights into reasons for year to year variation in the occurrence of herbaceous leguminous flora in pine stands burned annually.

Planting of exotic or native shrubs offers a means of providing more and better browse on critical deer ranges in the Black Hills, South Dakota. Curlleaf mountainmahogany (Cercocarpus ledifolius) shows promise after limited greenhouse and field planting. Seeds of this species, collected in northeastern California, were tested along with bitterbrush and true mountainmahogany (Cercocarpus montanus) in greenhouse trials. Cold stratification of seeds of curlleaf mountainmahogany in moist sand at 40° centigrade for 87 days gave 65 percent germination and 85 percent germination after 132 days, which compared favorably with germination of true mountainmahogany and bitterbrush. Survival of these species the first year in the field was: curlleaf mountainmahogany 84.7 percent, bitterbrush 65.1 percent, and true mountainmahogany 69.0 percent.

In central Colorado, mule deer used the big sagebrush type heavily during the winter of 1964-65 which was one of exceptionally deep snow. Severe starvation losses resulted when the animals were restricted to this type of winter range. In contrast, 1965-66 was a relatively open winter and most deer remained higher where snow was only 1 to 1.5 feet deep and where there was a greater variety of food and cover--aspen, conifers, and mixed shrubs. There were virtually no starvation losses in this winter. These observations suggest that snow depth may govern the winter condition of the deer herds and that modification of sagebrush range to benefit deer herds would have an effect only in occasional winters; however, in severe winters these practices may be extremely important.

Bitterbrush plantings on deer winter ranges in Oregon often fail because they are overused before they have a chance to mature, and because they cannot thrive under the severe competition afforded by surrounding vegetation. Removal of competing vegetation and protection from browsing for a short period provided a gain of 80 pounds of browse per acre. These responses after 2 years were from 6-year-old plants which averaged only 9 pounds per acre before treatment as a result of 75 percent average annual use. Grazing capacity was about 2 deer-days per acre on the untreated area as compared to approximately 18 deer-days under the combined treatments--a ninefold increase.

Topping appears to be an applicable management technique for greatly increasing the productivity of old bitterbrush plants which contribute little to the available browse supply on deer winter ranges in southern Idaho and adjacent Western States. Removal of approximately one-half of the upper crown canopy by cutting resulted in a ninefold increase in annual twig growth the first year. In subsequent years, topped shrubs outproduced control shrubs, but at a declining rate. Field tests revealed that topping could be accomplished about twice as rapidly using light-weight chain saws instead of lopping shears. By the chain-saw method, at a wage of $3 per man-hour, costs varied from $7.20 to $16.80 per acre.

Common gallberry (Ilex glabra), which occurs frequently in forests from Louisiana to Massachusetts, is worthless for cattle, is a physical barrier to good forest land management, increases the hazard and intensity of fires, and competes with desirable forage and trees. As described in a bulletin prepared by the Chemical Plant Control Subcommittee of the Range Seeding Equipment Committee (USDA and USDI), it can be killed by foliage spraying with a low-volatile ester of 2,4,5-T at rates of 2 to 4 pounds per acre. Burning temporarily eliminates top growth, but resprouting following the burn is profuse. Burning in March increases the effectiveness of chemical spraying in August.

Another problem shrub, saw-palmetto (Serenoa repens), competes with timber and forage over several million acres from Florida to South Carolina and Louisiana. It can be killed by double chopping or spraying with 2 to 4 pounds of 2,4,5-T; 20 pounds of dalapon; or 120 pounds of erbon per acre. Water appears to be the best carrier for 2,4,5-T and erbon, and a 1:1 ratio of water and oil for dalapon. For all three chemicals, 50 to 60 gallons of liquid per acre is suggested.

Development following a prescribed forest fire in Idaho revealed dominance of postburn vegetation by plant species sometimes not even recorded on the site before burning. Snowbrush ceanothus (Ceanothus velutinus) and Moldavica parviflora were recorded sparingly at most before the fire, but these two species now make up the largest proportion of plants on the site. Seeds in the duff or buried in the soil were not destroyed by the hot August fire, and apparently fire was necessary to break dormancy of the stored seed. However, while these species do well following a fire, they are intolerant of overstory shade. They decline as timber species become dominant, leaving an abundant seed supply to lie dormant until the next fire.

Fire was used to dispose of logging slash on a small tract in the Virginia Piedmont. A comparison of the amount of small game food on the burned area with that of an unburned control area showed 2,205 plants and 44.9 pounds of seed per acre were produced on the burned area compared with 337 plants and 5.6 pounds of seed per acre on the control. The first growing season after cutting and burning there were 2 coveys of quail (34 birds) and approximately 400 doves using the area for an important and striking increase in habitat quality and game response.

The Great Basin tent caterpillar (Malacosoma fragile) periodically causes very serious damage to bitterbrush in California. These infestations are particularly serious on deer winter ranges where the bitterbrush is already in poor condition. An epidemic is apparently developing--on some areas 54 percent of the bushes have tents. A native virus which often checks such epidemics has not yet been found in the current infestation. Plans are being made to introduce this virus experimentally.

2. Integration of wildlife, livestock, and timber production

Successful integration of wildlife and timber production in the various forest types requires information on effects of timber stand structures on forage and mast production and on reciprocal effects of wildlife on timber production. In order to harmonize use by livestock and wildlife (particularly big game), it is necessary to know the nature and degree of competition for forage at different seasons of the year and how management practices can be modified to allow most efficient utilization of the entire resource.

Clearcutting in the Southern Appalachian Mountains of North Carolina provides enough deer browse in the form of sprouts to allow seedlings of valuable timber species to develop. The first growing season after clearcutting, 991 pounds of available deer food were produced as well as over 6,000 stems per acre of important timber species. On another area 3 years after a heavy commercial cut, seedlings were almost four times as numerous as sprouts, yet received only one-fourth the use by deer. A 1-acre clearcut was too small to provide sufficient browse in the form of sprouts to allow a satisfactory supply of seedlings to develop, but clearcuts ranging in size from 20 to 55 acres had a surplus of browse and adequate timber regeneration.

Small clearcut openings in the spruce-fir and lodgepole types in Colorado receive greatly increased use by deer and elk. Cut and uncut strips 2 and 3 chains wide were used more by deer than strips 1 and 6 chains wide. Highest use by elk was at the 3-chain width both cut and uncut. Information of this nature will better coordinate timber management and wildlife habitat management objectives.

Deer are an important influence in determining the success or failure of regeneration of commercial northern hardwoods. The most desirable commercial hardwoods generally are those that deer prefer as browse. Simulated browsing of seedlings of four commercial species in Pennsylvania for 5 years showed that the most valuable species, black cherry, (Prunus serotina), was least able to maintain good form--even under low intensities of clipping. The form of white ash, (Fraxinus americana), sugar maple, (Acer saccharum), and red maple (A. rubrum) was less affected. The mid-levels of clipping intensity generally produced the best yields of deer browse. Survival rates were high in all species at all levels of clipping. However, the effects of heavy deer browsing stands can be serious because (1) any delay in stand establishment adds to the rotation period and (2) desirable commercial timber species may not grow out of the reach of deer.

Elk herds in northern Idaho depend upon transitory range which is created when the dense forest is removed by fire or logging followed by broadcast burning for slash disposal. On some areas it is feasible to maintain a relatively constant number of acres producing browse by integrated logging-wildlife management practices. Tree seedlings are usually visible on a site a few years after logging and can control a site within 10 to 15 years.

Meanwhile rapid growing species such as mountain maple (Acer glabrum) and Scouler willow (Salix scouleriana) provide forage for a few years but then grow out of reach of the animals. Wildlife values devolve on plant species subdominant in the stand. The major species for a few years is often snowbrush ceanothus which slowly declines as the timber species overshade the site.

In eastern Oregon and Washington, overstocked stands of ponderosa pine produce a preponderance of pole-size trees and very little understory forage. Seven years after thinning, stands left with a 13-foot tree-spacing produced 485 pounds of herbage per acre compared to 192 pounds for an unthinned stand. Those thinned to 18- and 26-foot spacing produced 550 pounds, about half of which is pinegrass, (Calamagrostis rubescens), a desirable forage. Bitterbrush, an important shrub for winter deer food, has increased from only 2 pounds per acre on the unthinned stand to as much as 50 pounds on the thinned area. This benefit will continue to increase as the young shrubs mature, whereas the rate of increase in the grasses and forbs began to level off between the third and seventh year following tree thinning.

In a selectively logged ponderosa pine forest in northern Arizona, cattle droppings were more numerous on areas cleared of slash; deer pellet groups were greater where slash was not disturbed. Slash cleanup had no measurable effect upon total amount or composition of understory forage and does not explain the differences in animal use. The physical obstacle of slash may, however, have contributed to use differences. Cattle prefer areas with lesser amounts of litter and logging debris.

3. Evaluation of wildlife habitat

The value of various habitats for the production of wildlife can be estimated in a number of ways. Quantities of herbage, mast, and berries and their chemical composition are important indicators of productivity, especially if food preferences and requirements for various species of wildlife are known. Likewise, actual observations on use of food and cover can provide information on habitat value. However, reliable methods for measuring and sampling forage production and utilization must be devised before adequate appraisals can be made.

a. Quantity and quality of forage. Fall-winter diet of California quail, an important and widespread upland game bird in the Western States, was studied on the San Joaquin Experimental Range in California during November, December, and January for 5 years. Diet components were separated into seeds and leafage. In wet years, seed of filaree (Erodium cicutarium) and turkey mullein (Eremocarpus setigerus) formed more than 50% of quail diet, but made up only 6% in dry years. Filaree was abundant in all years, but early rains in the relatively drier years, 1960-1963 caused germination and reduced availability of this seed. Strigose lotus (Lotus spp.) seed was

the most important food item in the dry years, but was only a trace item in a wet year. Far more green leafage was taken in November and December in dry years. These studies will be of particular value in relating livestock grazing practices to quail habitat and means for its improvement.

Extensive oak forests in central Lower Michigan lie close to major population centers and hunter and other recreation use is increasing rapidly. Studies of the oak type show that it has considerable potential as wildlife habitat, especially when crown cover is reduced by periodic cutting. Crown cover greater than 70 to 80 percent inhibits most taller browse production and tree reproduction. The overstory has less influence on low growing species such as blueberry, (Vaccinium spp.), huckleberry, (Gaylussacia spp.) and sweet fern, (Comptania spp.). Browse production in the oak type ranges from only a few pounds to as much as 300 pounds per acre. A large portion of this material (often over 50 percent) is low browse. Thus, the carrying capacity of the range varies drastically with winter conditions and is reduced considerably when deep snow covers the low shrubs.

Even-age management of northern hardwood stands contributes to the acreage in forest openings, which are preferentially used by deer in Pennsylvania. Partly this is a preference for open-grown browse. Deer further discriminate generally by eating only the tips of the terminal shoots of woody plants. Chemical analysis of the twigs of black cherry seedlings showed that the apical bud contained 20-25 percent crude protein, while the first inch of the twig contained 12-16 percent and the 3- to 6-inch section less than 10 percent. Red maple apical buds contained above 10 percent crude protein, with gradually diminishing amounts in successive sections of the twig to about 5 percent in the 9- to 12-inch section. Differences in geographical site, and location on the plant (terminal or lateral) apparently had slight influence upon protein content. While deer prefer red maple twigs over those of black cherry, a diet that includes both species could easily satisfy the suggested protein requirement.

To determine nutritional levels of important browse species and how these levels are affected by various factors during phenological stages of development, plant species browsed by mule deer were sampled at four seasons from five study areas in the Poudre River Drainage, Colorado. Collection sites ranged from low elevation winter range to high elevation summer range. The percentage dry matter, crude fat, and the caloric content varied from high autumn-winter levels to low spring-summer values. The beta carotene and percentage protein, ash, phosphorus, potassium, calcium, sodium, and magnesium levels varied from low autumn-winter values to high spring-summer values. From multiple regression analysis, crude protein content was found directly related to phosphorus and inversely related to levels of crude fat, magnesium, and dry matter. Caloric content was directly related to crude fat and phosphorus and inversely related to the percentage of ash.

In feeding three artificial diets to mule deer in Colorado, it was found that both digestible energy and digestible dry matter were inversely related to dietary cellulose content. The diets varied in cellulose content, but were similar in protein and energy levels. Thus, the normal seasonal variation in the fiber content of natural forages appreciably influences the nutrient availability of these forages to deer. Basic findings such as these have worldwide implications for providing information on the most nutritious forage for deer and similar wild ungulates.

Stomach collections from 30 mule deer in Colorado indicated a higher rate of rumen fermentation during the growing season when range forage was succulent. Conceivably this is accompanied by a greater turnover rate of rumen contents which would provide considerably more energy to deer at this season than during the winter. The results stress the need to furnish deer with a low-fiber, easily fermented food during the winter when the fat and metabolic energy content of forage is usually low.

Crude protein and phosphorus are often used as indicators of forage quality, which in turn signifies animal production potential. In rusty blackhaw (Viburnum rufidulum), a common browse plant of forests in east Texas, the crude protein and phosphorus content was higher in the terminal inch of the twigs and the attached leaves than in segments 2 and 3 inches from the tip. Leaves were higher in protein than the twigs. The results emphasize the need to carefully select the portion of the plant being eaten by the deer when evaluating forage quality. Also when deer consume the older portions of the plant as they often do on overgrazed ranges, they are ingesting a much lower quality forage than would normally be consumed on properly stocked ranges.

Food deficiencies develop in the Arizona chaparral community during the May to June drought period after spring growth of shrubs has ended and before summer growth of herbaceous plants begins. Fire sprouts of shrub live oak, (Quercus turbinella), birchleaf mountainmahogany, (Cercocarpus betuloides), and Wright silktassel (Garrya wrightii), are utilized by white-tailed deer during this period, with mountainmahogany preferred. During periods of heaviest use, crude protein content of preferred sprouts was about 12 percent and calcium content was above 0.75 percent, relatively high values for deer nutrition. Provision for small areas on which there are chaparral sprouts, preferably mountainmahogany, should improve attractiveness of the chaparral habitat for deer.

Protein and phosphorus appear to be the nutrients most deficient on the McVey Burn winter deer range in the central Black Hills. Of the important browse species only fringed sagebrush (Artemisia frigida) was believed adequate to meet the requirement for deer during the fall season. Fringed sagebrush had 9.5 percent protein, chokecherry (Prunus virginiana) contained 8.3 percent protein and woods rose (Rosa woodsii) and aspen (Populus tremuloides) tested 4.8 and 5 percent, respectively. Common snowberry

(Symphoricarpos albus) and western snowberry (Symphoricarpos occidentalis) each contained about 6 percent. During the growing season the protein content of the shrubs met or exceeded the requirement which is believed necessary for deer.

During the spring and summer all the shrubs met or exceeded 0.22 percent phosphorus. In the fall only aspen was less than 0.17 percent, while during the winter dormant season only chokecherry with 0.20 percent phosphorus approached the 0.21 percent which is expected necessary for deer in early gestation. All shrub species contained ample calcium content at all collection dates. This was also true for gross energy.

b. Habitat utilization. Three years of seasonal observations on big-game use in the Blue Mountains of Oregon showed that less than two percent of available forage in any of the three types: grassland, open forest, and dense forest, was used. Although as many as 40 species were used in a particular type and season, only 5 or 6 constituted the major part of the diet. In the spring the grasslands received the heaviest use as big game sought out succulent forbs. When grassland forage began to dry and mature in late spring and early summer, the animals shifted to the forested types in search of later maturing forbs, elk sedge, (Carex geyeri), and several species of low-growing shrubs. Although the dense forest offered heavy cover as well as a variety of forage plants, deer and elk preferred the open forest during the summer and fall. Elk sedge, also an important cattle food, made up more than half of the open forest diet. Low-growing shrubs were important in the dense forest. Where livestock and big game use the same area, this knowledge of what the animals eat and when they eat it is especially important for management guides on several million acres.

A study of the influence of cattle use and habitat differences on big-game distribution in the Pacific Northwest revealed that, as cattle use increased, use by elk decreased significantly. At light rates of cattle use, elk preferred pastures that were grazed seasonlong, but at heavy rates of cattle use they preferred those grazed on a deferred-rotation basis. Deer showed only a week preference for cattle units under deferred-rotation as opposed to seasonlong grazing.

Cattle may be used to reduce perennial grass competition in bitterbrush plantings on Great Basin deer winter ranges in northeastern California to create a better environment for seedling establishment. One of the keys to this approach is the time when cattle use grass or bitterbrush. Based on actual observations of animals, browsing generally followed the bitterbrush growth curve. Cattle use was practically nil before leader growth started in April, but climbed to almost half-time spent on bitterbrush in early June. Use then decreased erratically to about one-fourth of the animals' grazing time being spent on bitterbrush by the end of growth in September. Therefore until bitterbrush plantings become well established, cattle grazing should be curtailed until fall.

Trials in central Oregon with known numbers of deer in fenced areas showed a stocking rate for winter grazing of 31 deer-days per acre, based upon the criterion of 60 percent use of bitterbrush leader length. Concurrent trials of spring grazing by cows showed a stocking rate of 9.5 acres per AUM at which time they had used 40 percent of the bitterbrush and only 25 percent of the grasses. An additional seven days of cattle grazing were required to obtain the desirable goal of 40 percent use on grasses, but this increased total (deer plus cattle) bitterbrush use to 85 percent, which is usually considered detrimental to this very important deer food. Thus, although deer and cattle do not compete directly for bitterbrush because they are not on the same area at the same time, and although some cattle grazing in the spring is desirable to utilize grasses and forbs, the cattle should be removed before they overuse the bitterbrush.

Mule deer grazed more than 30 planted species on their winter range in central Utah. Preference changed as the season advanced into early spring. It was apparent that the presence of highly preferred species, such as bitterbrush, cliffrose (Cowania mexicana), fourwing saltbush, or curlleaf mountainmahogany is probably not essential for a range to support a thrifty game herd if there is a good variety of less-preferred species and big sagebrush. At a lower site, deer showed a particular appetite for a number of forbs and grasses. Among these were small burnet (Saponaria occidentalis), Palmer penstemon (Penstemon palmeri), squirreltail (Sitanion hystrix), intermediate and crested wheatgrasses, and orchardgrass (Dactylis glomerata). In several spots deer pawed through the snow to graze these herbs. Stomach contents of two deer, which had been grazing seeded ranges in January, showed high proportions of grass in their stomachs. In addition to green leaves, it was surprising to find seedheads of smooth brome (Bromus inermis), the two wheatgrasses and a considerable amount of alfalfa seed burs.

The length of deer use of winter range in the Black Hills is greatly affected by early winter snow storms. The fall and early winter of 1965 was relatively snow-free and deer stayed on the summer range well into February. The previous two winters deer were forced to commence using the study area by late December and remained through late May - a period of approximately 150 days; deer winter use was estimated at 43.6 deer days per acre. Deer use dropped to 22.8 deer days per acre during the winter of 1965-66; the animals still did not leave the winter range until May, but remained to feed upon the new spring growth. Indications to date suggest, therefore, that the condition of the winter range is determined primarily by the date of deer arrival in the fall or winter.

Home range instinct is strong in mule deer and once they have established a home range they habitually graze certain areas year after year. For example, in Utah they prefer to graze in and adjacent to protective cover in winter unless they are forced to forage out in open valleys to obtain food.

On summer range aspen and mountain shrub types were preferred to all others. Steepness and roughness of slope have little direct effect on deer distribution unless there is also a lack of suitable forage. Slope and aspect influence seasonal movements of deer on summer range by affecting stage of growth of forage plants. On winter range exposure affects snow depth, temperature and wind movement; consequently it influences distribution of deer. Water has little effect on mule deer distribution in winter and spring or in the summer as long as they have green feed.

A measure of the importance of the more than 90,000 stock watering ponds in South Dakota as waterfowl habitat was obtained from selected ponds which were visited 15 times during the April to October ice-free period of 1966. A total of 1,850 waterfowl and shorebirds were observed on 13 ponds and the average number of waterfowl and shorebirds per visit was 9 birds per pond. The ponds supported approximately 25,000 bird-days by 29 species.

c. Vegetation measurement and sampling. Fecal samples were collected of 17 forage species, including grasses, forbs, shrubs, and trees, that had been fed individually to captive white-tailed and mule deer in Arizona. Recognizable morphological characters for all 17 species of plants appeared in feces under magnification of 0 - 100 X. These findings suggest that a fecal analysis technique may be developed to supplement rumen analysis and direct observation for determining food habits of deer.

Through direct animal observation, rumen and pellet examination and forage analyses, the potentials of forest habitats in Poland for red deer are becoming known (PL-480). Scotch pine (Pinus sylvestris) was the major item in the diet in the winter. Dwarf shrubs, such as whortleberry (Vaccinium myrtillus), were second highest at this period while other plants averaged less than 10 percent. By spring a large number of herbaceous dicots were the second highest component of the diet. Consumption of this group of plants continued to increase through the summer while tree browsing decreased. By autumn grasses and grass-like species comprised 40 percent of the diet while trees, dwarf shrubs and herbs each furnished approximately 20 percent.

A statistically reliable prediction of prebrowsed twig length of serviceberry (Amelanchier alnifolia) can be obtained from diameter measurements taken in the spring. Examination of 852 serviceberry twigs from 110 plants on 11 different sites in western Montana has demonstrated a very strong relationship between twig diameter and twig length. By combining this prediction with measurements of remaining twig lengths and with counts of the total percentage of twigs browsed, a very accurate estimate of total length utilization can be obtained. The potential value of this technique is that twigs need not be tagged and measured in the fall and only browsed twigs need be measured in the sample.

In other techniques aimed at reducing the effort of sampling shrub attributes through indirect measures, it was determined that the space occupied by the plant crown can be used to predict the weight of forage produced by serviceberry shrubs. The regression of grams annual growth on crown "aerial volume" varies from site to site, but is very consistent on any one site. Thus, by clipping a few shrubs it is possible to determine a mathematical relationship applicable to all plants on a site. And, since crown volume measurements can be obtained very quickly,the technique has potential for reducing the amount of time required to obtain production of browse ranges.

Clipping studies conducted in Montana show that the average serviceberry plant produces only 16.3 grams of new twig growth per year. Assuming a daily requirement of 4 pounds of forage, a deer would have to utilize 100 percent of the annual growth on 111 plants to obtain a daily ration. Twigs had an average weight of 222 milligrams and an average length of 95.68 mm. Based on these figures, a daily ration for a deer consists of more than 8,000 twigs, with a total length just short of a half-mile. Obviously, browsing must be concentrated on larger plants and on a variety of other species, as well, to satisfy the needs of the animals.

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III. FOREST PROTECTION RESEARCH

A. FOREST FIRE

Problem

Wildfires are a constant threat to our forests and wildlands, and affect every phase of national programs for the protection and management of these resources. Wildfires damage timber, watersheds, scenic beauty, recreation areas, rangelands and wildlife, and thus represent a tremendous drain on both these natural resources and public funds. Also, they often take a toll in human lives, threaten the safety of people in forest areas and suburban communities, and destroy buildings, utility lines and property values.

Great strides have been made in the reduction of fire losses since World War II. The average annual area burned during the 1940-50 period was almost 23 million acres. In the 50's this dropped to about 9.5 million acres, a reduction of 59 percent. The drop in the 50's was gradual but constant, starting with 17.5 million acres in 1950 and ending with a low of 3.5 million acres in 1958. But since 1958 there have been few gains. From 1959 to 1966 the acreage burned has averaged 4.3 million acres with 1966 having 4.6 million acres. Fire losses may even be on the increase in some areas. In the Rocky Mountain-Plains States area, 14,000 fires burned 995,000 acres in 1966, an increase of 36 percent over the 10-year average. This trend was also noted in the Pacific Coast States area where 961,000 acres were lost to fire as opposed to a previous 10-year average of 877,000 acres. The demands on all forest resources are growing, and increasing use results in a corresponding increase in the complexity of the forest fire problem.

The 100,000 fires per year on 1.2 billion acres of forest lands requiring protection result in a direct cost for wildfire control that currently exceeds $150 million. The major costs are incurred in fewer than five percent of the total number of fires. These are the runaway fires. Through research and development activities and energetic action programs by many agencies, effective methods have been developed to prevent, detect, and suppress the average forest fire. But, much more knowledge is needed to enable fire control specialists to identify the potential for runaway fire behavior. The effects of fuel, weather and topography on such fires are still beyond our grasp. The control of these effects can only be achieved through continued intensive research.

An important aspect of present day forest fire research activity is the unparalleled opportunity that exists for progress. Never before has there been more promise for developing new scientific approaches to the problems of protecting forests from fires. Advances in the sciences of physics, chemistry, meteorology, mathematics, engineering and forestry can all contribute measurably to progress in forest fire research. Space age technology in such areas as remote sensing, electronic systems, combustion physics and atmospheric sciences all provide new inputs to the development of more effective fire technology.

USDA and Cooperative Programs

The national program of forest fire research is performed by the Forest Service in cooperation with private, State and Federal agencies and universities. A major part of the research is performed at three Forest Fire Laboratories located at Riverside, California; Missoula, Montana; and Macon, Georgia, equipped with special facilities and manned by an interdisciplinary staff.

Forest fire research projects are also currently headquartered at College, Alaska; Seattle, Washington; Berkeley, California; Flagstaff, Arizona; St. Paul, Minnesota; Columbia, Missouri and State College, Mississippi. These projects are closely associated with programs at the Forest Fire Laboratories. They strengthen both national and regional programs through utilization of facilities and cooperative assistance available at these locations and the surrounding forest regions.

Federal agencies cooperating in the forest fire research program include the National Science Foundation, Environmental Sciences Service Administration, National Park Service and Bureau of Land Management. Much of the research has strong national defense aspects. Department of Defense agencies cooperating in the program include the Office of Civil Defense, Advanced Research Projects Agency, Defense Atomic Support Agency, U. S. Navy and U. S. Air Force. Several universities and state forestry departments also provide personnel, study areas, and specialized equipment. The states of California, Georgia and Missouri make direct financial contributions to the fire research program.

In fiscal year 1967 forest fire research provided 81 professional man-years of inhouse effort. In addition 4 professional man-years were financed by Forest Service funds for fire research by universities and other research institutions. This domestic program was supplemented by PL 480 funds in 2 countries totaling 44,900 U. S. Dollars equivalent.

Programs of State Experiment Stations and Schools of Forestry

A total of 1.5 scientist man-years is devoted to this area of research.

Progress-USDA and Cooperative Programs

1. Fire physics and chemistry

Scientists at the Northern Forest Fire Laboratory use high speed motion pictures to study wind tunnel fires in fuel beds of ponderosa and white pine needles. The photos show that if the wind is strong enough to overcome the natural buoyancy of the fire, the flame is tilted and hot gases and leader flames intermittently contact the fuel ahead of the fire. This action is believed to provide a large percentage of the heat necessary to raise the fuel to ignition temperature. In the absence of wind, this mechanism of heat transfer is not available, and the fire spreads much more slowly. Results of these experiments are providing a basic understanding of the mechanisms of fire spread.

A similar study has shown that the rate of fire spread depends on radiant heat from both the flame and from the solids within the fuel bed. When no wind is present, the flame size, emissivity and temperature affect fire spread. Some success has been achieved in mathematically describing these processes.

Scientists at the Southern Forest Fire Laboratory investigated the effects of moisture content and fuel loading on fire spread and found that for no slope, no wind fires, 80 percent was the critical moisture content at which fire spread ceased for wood densities around 26 pounds per cubic foot. This figure is considerably higher than presently accepted values. This basic research is providing fire control personnel with information on how fires react to wind, topography and moisture content of fuels.

The pyrolysis and combustion characteristics of cellulose have been studied for years with conflicting results. When samples undergo a complicated set of simultaneous and sequential reactions, as cellulose does on heating, results of standard chemical analyses are difficult to interpret. Comparisons of pure and contaminated samples, pyrolyzed under identical conditions reveal that the most effective chemical flame retardants lower the temperatures at which glowing and charring occur. This means that the total damage to treated wood materials exposed to a small fire may actually be greater than that of untreated wood. As little as 0.15 percent inorganic contamination can significantly affect the pyrolysis reactions undergone by cellulose. The addition of 1.5 percent potassium bicarbonate lowers by some 80° C. the temperature at which rapid decomposition begins, but essentially eliminates the flame-producing reactions in favor of those leading to glowing combustion. Some retardants, then, actually increase rather than retard combustion. But, as glowing combustion is easier and safer to suppress than flaming combustion, the effects are still beneficial to the fireman.

Related research in Israel under Public Law 480 includes isothermal pyrolysis experiments on pure and retardant-treated cellulose in various atmospheres. These experiments have led to the development of a new gas chromatographic method employing inert internal standards for the quantitative analysis of α and β-d-glucose mixtures. Scientists have shown that by using C^{14} labelled glucose, the gaseous pyrolysis products originate preferentially from the C_1 position, while the C_6 position largely remains in the residue. In addition, they have constructed an apparatus which will permit simultaneous differential thermal and thermogravimetric analyses of cellulose samples.

On the more immediately practical side, fire retardants may be capable of providing additional benefits in slash disposal. Recent large-scale studies in Oregon and northwest California have shown that light treatments of water solutions of diammonium phosphate applied to slash have reduced the rate of combustion by about 90 percent. But, in spite of this reduction in burning rate, more treated material was eventually consumed than in similar but untreated, adjacent fuels. In the future, we may be able to control the combustion of large concentrations of fuels on prescribed fires and wildfires.

2. Atmospheric physics and forest fire meteorology

a. Lightning Seven individual lightning discharges that caused forest fires in 1965 and 1966 near Missoula, Montana, were described and measured. All of these discharges exhibited a continuous long period current flow supporting the hypothesis that this particular type of discharge is especially effective in causing forest fires. These findings were obtained as part of the continuing research of lightning storm characteristics wherein scientists are studying the relationship between intensity of radar echoes and the type and frequency of observed cloud-to-ground lightning discharges. An analysis of strong, moderate and weak echoes and the number of cloud-to-ground discharges near the Point Six radar station at Missoula, Montana, showed that the more intense the radar echo, the higher the number of reported discharges. However, three years of radar and lightning fire data from the Nezperce and Clearwater National Forests in Idaho showed that most lightning fires are associated with weak radar echoes and that no lightning fires are associated with strong echoes.

These results present several questions that need to be answered. Are the long period lightning strokes that start fires associated with weak radar echoes, or do strong radar echoes simply mean that there is sufficient precipitation to prevent fire starts? Do specific types of lightning strokes come from particular storm types, and if so can these storms be identified in advance? Further research is designed to answer these questions.

Four years of data are now available from experiments aimed at determining the possibility of preventing or reducing the number of lightning-caused fires by cloud seeding. Analysis of the frequency of cloud-to-ground lightning shows 1,073 discharges during periods of no cloud seeding with silver iodide and 718 discharges during periods of cloud seeding, a difference of 33 percent. This encouraging difference still does not satisfy rigorous statistical tests because of limited test design and sample size. In order to fully evaluate the potential of cloud seeding a larger scale experiment is planned together with continued emphasis on the more basic research in thunderstorm processes. According to several theories, massive glaciation is required to modify the electrification of lightning storms. In current experiments, cloud measurements have been obtained which show that such massive glaciation is being achieved at desired temperature levels by high output silver iodide generators and cloud seeding technology developed by Forest Service Scientists.

b. Fire weather patterns Almost 50,000 forest wildfires burned in Georgia during six "moderate" fire years. Less than 250 of these burned a total of 45,000 acres on a relatively few extreme weather days. Transient weather events and small scale meteorological features act as triggering mechanisms of violent fire behavior associated with most large forest fires. Payoffs in such research of local atmospheric events depend heavily on establishing a network of meteorological stations scaled to the size of the events to be studied. Scientists in Georgia have found that a single or multiple cellular atmospheric event such as a thunderstorm is of the same scale as a three dimensional forest wildfire. This information provides guidelines for design of a meteorological station network. Research on the physical mechanisms of small-scale weather factors, such as those associated with dry cold fronts, sea breeze fronts, vorticity maximums and convergence situations, is aiding in forecasting the associated fire behavior problems. Such forecasts can be issued for specific areas and specific time periods by a national or large regional forecast center, whose primary responsibility would be the forecasting of the more extreme categories of fire weather.

Research at the Riverside Forest Fire Laboratory in California has found that the sea breeze front along the Pacific Coast has a dual structure on clear days when the marine layer is shallow and is subjected to intensive daytime heating. This heating causes the zone of strong temperature gradient to remain near the coast, while the front, with its attendant wind shift and increase in speed, continues to move inland. This explains the observed wind shift without lower temperatures and higher humidities, a phenomenon which has been responsible for several fire disasters in Southern California. This study has also shown that the synoptic weather pattern affects the sea breeze circulation and the temperature regime. Synoptic patterns with an onshore component favor a deep marine layer and therefore less air mass modification

by heating. Offshore components favor shallow marine air layers and greater modification. Strong offshore components may entirely prevent marine air penetration. This information now enables fire control personnel to recognize this phenomenon and prepare for it.

Another study in California analyzed aircraft and pilot balloon observations taken during days on which downslope afternoon winds occurred in the coastal mountain ranges. This analysis shows that there are three distinct flow regimes: a valley wind stage; a transition stage when the sea breeze combines with the valley wind; and a wave stage. Air begins to stream over the ridge during the transition stage in response to further heating inland. Also, waves became imbedded in the flow just downwind of the ridge.

Analysis of the convection associated with the valley wind regime at the Riverside Forest Fire Laboratory shows that numerical simulations can be used to approximate most of the features and processes of the valley wind system. The valley wind reaches a quasisteady state in the afternoon, which apparently results from a maximum rate of conversion of potential to kinetic energy.

3. Fuels and fire behavior

a. Fuels Dense understory vegetation affects fire behavior, impedes fire control efforts, and reduces visibility. Information on the kind, height and density of understory vegetation is needed both to plan broad-scale fire control systems and to devise strategy and tactics in suppressing individual fires. At present, there are no techniques for obtaining this information with acceptable speed and cost.

A research study in Washington showed that the height and density of understory vegetation beneath a dense hardwood canopy could be determined and mapped with reasonable accuracy from large-scale color aerial photographs. Both natural-color and false-color photographs were used at scales of 1:2,000 and 1:3,500. The natural-color at 1:3,500 permitted estimates of understory height and density that compared reasonably well with observations on the ground wherever canopy density was less than 90 percent. Larger canopy openings were required for measuring understory height than for estimating density. A larger scale than any of those used in this study, probably about 1:1,000, will be required to identify understory species. Fire control personnel may soon have the ability to evaluate understory conditions accurately in order to determine firefighting methods and locate potential control lines on large wildland fires. Also, these techniques will prove useful in broad-scale mapping of fuel types as a basis for fire control planning.

At the Forest Fire Laboratory, Missoula, Montana, identical physiological development and drying response of cheatgrass in Idaho, and western Montana was observed. The only major difference was the calendar date when curing started, which was weather- and site-dependent. The onset of flammability could be indicated by changes in coloration. Results of this study will give fire control personnel knowledge of the precise changes in flammability of cheatgrass which occur with changes in season and weather.

b. Fire behavior The Project Flambeau staff at the Riverside Fire Laboratory conducted an experimental mass fire that involved 4800 tons of fuel in 240 piles covering 30 acres. This was part of a jointly sponsored research program by the Forest Service, Office of Civil Defense, and Defense Atomic Support Agency. All piles were ignited within 32 seconds, and the peak burning rate occurred within five to six minutes. The fire produced a convection column that reached an altitude of 16,000 feet an hour later. Data collecting and recording systems, designed specifically for the extreme mass fire environment, produced a series of observations of airflow, temperature, burning rate and other data on the behavior of the fire. Stainless steel vector anemometers, used because of their ability to withstand high temperatures, performed well in the heart of the fire area. Weightloss platforms and a continuous flow water calorimeter were tested for the first time, and showed particular promise for collecting data on burning rates. New emphasis is being given to the theoretical and analytical aspects of mass fire behavior. For example, one study is using a simplified theoretical model of convection energetics to examine the transition zone between the tips of the flames and the fully developed smoke column. Initial results of this analysis indicate two modes of convection: a mode below the transition zone determined by individual heat sources, and a mode above determined by the more homogeneous buoyancy distribution at the top of the transition layer.

A Public Law 480 project in Spain has derived analytical expressions for the burning rates of liquid fuels in open vessels as functions of the physical properties of fuel, the radiant characteristics of the flame, and vessel diameter. The findings show that seemingly conflicting results reported by different investigators were the result of their individual experimental techniques. Scientists on the project also used special horizontal and vertical wind tunnels to determine the life histories and free flight patterns of burning wood firebrands of different sizes, shapes and densities.

4. Fire Prevention and Use of Fire

a. Man-caused Fires A pilot study in Mississippi to analyze patterns of fire prevention activities for future research and action programs revealed: (1) fire prevention activity was held at an approximately constant annual

level for the 5-year period 1960-1964; (2) intensity of the activity varied considerably by month and season within and between years; (3) maximum effort occurred during October through April for all years; and (4) variations in intensity for the different media over the same period within years indicated a lack of consistency.

Children-caused forest fires are a growing problem in the Los Angeles area, as in other parts of California where forest use is increasing and residential developments are extending to the fringes of forest covered land. Analysis of fire causes for a five year period shows that children-caused fires accounted for 15 percent of the fires. On one California Division of Forestry district over one-fourth of the fires were started by children. In another district 643 children-caused fires burned 34,588 acres. Surprisingly, children ten years or younger started about three-fourths of the fires attributed to juveniles, with the highest incidence occurring among the 5 to 7 year olds. The public school conservation education program is generally focused at the fifth grade (11-12 year old) level. It is now evident that new methods are needed to reach the younger children, including those of pre-school age.

Local residents of forest areas cause a disproportionately high number of forest fires in California (and in most other states as well). To obtain an understanding of the causes of this situation, researchers conducted a study of fire hazard inspection procedures in Butte County, California. The study included various combinations of advance fire prevention letters to residents, hazard inspections, follow-up letters and follow-up inspections. The advance letters had no observable immediate effect. Sixty-three percent of the properties initially inspected were found to be in violation of at least one provision of the State of California's Public Resources Code. About four-fifths of these violations were for failure to clear dry grass and debris from the immediate vicinity of buildings, while 17 percent were due to non-standard incinerators. As a result of the initial inspection, 35 percent of the violators cleaned up their properties within 10 days. A follow-up letter resulted in compliance from an additional 15 percent of the violators. But a follow-up inspection after 10 days resulted in 80 percent compliance. The hard core 20 percent required legal action. This information will help administrators to reduce fire code violations and, in turn, to prevent forest fires.

b. Use of fire and hazard reduction More than two million acres of forest and range land in the South are being treated annually with prescribed fire. Environmental conditions and firing techniques are the major factors governing the success or failures of this type of treatment. To better understand these influences and to develop improved firing techniques, research is maintaining a continuing program in prescribed fire research. Researchers have

also discovered that, contrary to popular opinion, lines or spots of fire spaced close together create higher burning intensities and greater crown scorch and damage in overstory pine canopies than widely spaced fire sets. It is not the momentum of the individual fire sets, but rather the junction zones, that create damaging intensities. Thus, success in achieving the desired fire intensities can be enhanced by regulating the extent and spacing of fire sets within an area.

A newly developed technique in prescribed burning known as "chevron burning" is showing promise as an effective and economical means of controlling understory plant species and preparing seedbeds in the Piedmont country of the Southeast. This technique resembles the spokes and hub of a wagon wheel with the hub at the highest point of the area. The hub is ignited first and then the fire is carried down hill on all sides in lines that produce the spokes.

In the arid Southwest prescribed fire is a potentially efficient tool capable of performing several land management jobs. These include the conversion of brush to grass, increasing the food supply for stock and wildlife, reducing the fire hazard, and in some situations increasing water yield. In studies aimed at extending the time of year that this tool may be made available to land managers, scientists in Arizona have found that a 2, 4, 5, -T diesel oil treatment applied to scrub live oak in January consistently raised the energy value of the solid material in the leaves. The treated leaves yielded one percent less crude fats, and, when burned in an oxygen bomb calorimeter, produced 2.3 percent more energy. Further research is required to determine whether this energy change is due to additives from the diesel oil, chemical modifications of the leaves, or both. Results from this study may make it feasible to extend burning into wintertime.

Although prescribed burning is an effective and relatively cheap tool for many land management jobs, serious questions are being raised about the effect of all this smoke on national air pollution problems. All three forest fire laboratories, in cooperation with the Department of Health, Education and Welfare and various University groups, are initiating studies on the effects of forest fire smoke on air quality.

Some jobs can be done without using fire. Chaparral-to-grass conversion, for example, requires the effective use of herbicides. A study at the Forest Fire Laboratory, Riverside, California, tested Picloram, in both spray and pellet forms, for its ability to kill chaparral species at several sites. This herbicide proved to be as effective as the old standard brushkillers, or slightly more so. Both herbicide forms killed chamise readily at low rates, but failed to kill scrub oak. Kill of other species varied between these two extremes. At one site, excellent kill was obtained of all species after re-treatment with Picloram. Picloram, thus gives promise of being a valuable

woody plant control and may reduce the cost of controlling shrubs resistant to other herbicides.

Plant growth inhibitors show considerable promise as a method of fuel hazard reduction. In laboratory experiments maleic hydrazide proved to be the best of several inhibitors. It reduced the growth of black sage by as much as 94 percent and was equally effective on scrub oak. In another experiment, sage cuttings were treated with a one percent solution of three different inhibitors, and then were sectioned for microscopic examination. This examination disclosed that maleic hydrazide completely stopped growth; phosphorus reduced the growth rate; and cycloeal had no effect. The next step in this program will be field testing of maleic hydrazide to establish proper procedures and application rates.

5. Fire control methods and systems

Since fire retardants were first proposed for use in the control of forest fires, a multitude of formulations have been developed. Various testing procedures have been used over the years, ranging from the burning of ¼" wooden dowels in special ovens to elaborate and expensive field tests, to determine the effectiveness of these different formulations. Now the Northern Forest Fire Laboratory has developed a new method for ranking relative fire retardant effectiveness. This method compares rate of fire spread, rate of weight loss and radiation from burning treated fuels to those of untreated fuels, resulting in an equation that represents a "superiority factor". Preliminary results show that the chemicals' effectiveness on these fuel bed tests rank similarly to the results from microsamples subjected to the more difficult differential thermal analysis and thermogravimetric analysis procedures. These analyses, as well as the expensive field testing, are now being replaced with this new method.

Fire retardant chemical research at the Southern Forest Fire Laboratory is currently aimed at finding the quantity of retardant needed to slow or stop the spread of fire in the fuel types common to the South. Scientists have determined that a ground fire tanker, pumping a 15 percent solution of diammonium phosphate, can establish an effective fireline 30 feet wide at a maximum rate of 10 mph. While conducting this study, the researchers also discovered that strip fires set parallel to the prepared chemical line rapidly extended the effective control line width. This control technique of combining chemical line with burned out strip can make a firebreak nearly 200 feet wide.

Helicopters are being used at an increasing rate for dropping water and fire retardants on wildland fires. In comparison to fixed wing aerial tankers, the helicopter can make drops faster, make them more accurately, and make them

at less cost. A big factor in reducing costs is that helicopters are not restricted to operating from standard airports. A temporary heliport with retardant mixing equipment can be set up close to the fire, and thus greatly reduce the flying time required for each retardant drop. However, the most effective retardants contain either ammonium phosphate or ammonium sulfate which are moderately corrosive. Helicopter pilots have, therefore, shied away from using the best retardants for fear of corrosion to delicate aircraft parts. Scientists at the Forest Fire Laboratory, Riverside, California, have conducted a study to determine the extent, if any, of this problem. Using micro-residue techniques and fluorescent dye mixed with the retardants, the study determined the quantity of dye reaching small pieces of mylar tape placed in various spots on the aircraft. The results of this new study show that under most fireline conditions little or no retardant reaches the helicopter. Now, helicopter pilots may use these types of retardants without fear and materially increase the effectiveness of their aircraft.

Analysis of the fire danger rating system for Alaska, based on the indexes used in the national system, has shown that there are significant differences in fire danger patterns among the 21 fire weather stations in the interior. These differences are great enough to suggest that composite statewide data should not be used as a planning base. Instead, areas having similar index characteristics should be used for fire control planning.

One of the major difficulties associated with fire danger rating is the determination of the fire danger at any place on a land management unit and at any time of the day. Data used to determine fire danger are usually collected at only one or two fire weather stations within a management unit, so that the information collected at one location does not provide a true picture of fire danger at a different location. Also, there is no standard method of determining the fire danger several hours after the weather data are recorded. To solve this problem, the Northern Forest Fire Laboratory has developed a meter to be used with the national fire danger rating system. This meter converts spread index from one place and time to another, such as to the site of a fire from a valley bottom or mountain top fire weather station. In addition, it converts this index to any time up to 12 hours after the index is computed.

Researchers in California have conducted a theoretical study to determine the costs and benefits to fire protection of adding roads, fuelbreaks, tractor lines, fire stations and combinations of these facilities to the existing fire control system on the Los Padres National Forest. This National Forest has experienced several major fire disasters in the recent past due to the hazardous nature of its fuels and topography. The object of this study was to determine ways of increasing fire protection coverage at least cost. Results showed that adding alternative systems of roads, fuelbreaks, and tractor lines

gave only a 1.1 percent increase in the area where initial attack can be made within required time limits, but added a 67 percent increase in costs. The addition of fire stations, however, increased coverage 13.4 percent with only a 14 percent increase in costs. The methods used in this study are also applicable to other high hazard wildland areas.

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B. FOREST INSECTS

Problem

Insects are among the most destructive agents affecting the Nation's forests, even as the forest lands themselves are becoming more valuable and their uses more numerous. Pressures for timber, water, wildlife, recreation, and esthetic values are increasingly greater. This means more intensive forest management and more intensive forest protection in the future. Insect-caused losses that we have accepted in the past can no longer be tolerated.

Damage caused by insects is not confined to timber values alone: watersheds and wildlife habitats are impaired; fire danger is increased; insects destroy the seeds and cones of trees, thereby jeopardizing the success of seed orchards and natural regeneration programs; they infest browse plants, lowering their value to livestock and game; and they damage or destroy huge quantities of forest products, such as logs, lumber, and pulpwood. Termites and wood borers invade dwellings; other insects infest shade trees and destroy scenic values in parks and recreation areas.

More and better information is needed on the causes of forest insect outbreaks, on long-lasting silvicultural and biological control methods, and on the development and improvement of chemical controls that can be applied economically and without undue hazard to man, fish, wildlife, and other nontarget elements of the environment.

USDA and Cooperative Programs

The Department has a continuing long-term forest insect research program involving forest entomologists as well as other researchers representing a broad range of the scientific disciplines. These scientists are engaged in basic and applied studies aimed at the development of safer, more economical, and more effective methods of reducing losses caused by forest insects. Research is carried out at the eight regional Forest Experiment Stations as well as at the Forest Products Laboratory; the effort totals 94 scientist man-years per year.

In addition, work is now being done under 15 grants for basic research (PL-934) at 10 universities and 1 research institute. Research is also being conducted under 15 PL-480 grants in 10 countries. These PL-480 studies include identification, collection, and shipment of forest insect parasites and predators, studies of the biology and ecology of pest insects and their parasites, and biology of certain insect pathogens. All of this research is closely related to the Forest Service program.

Active cooperative efforts in such forms as consultation services, land use, labor and facilities are in effect with many universities, State forestry departments and experiment stations, lumber and pulp and paper companies, and chemical companies. Agricultural Research Service cooperates in technical consultation on problems of mutual interest such as insecticides, insect identification, and in introduction of insect parasites and predators from abroad. The Canada Department of Forestry and Rural Development also cooperates in the introduction of parasites and predators and participates in consultations on common problems.

Program of State Experiment Stations

A total of 48 scientist man-years is devoted to this area of research.

Progress - USDA and Cooperative Programs

1. Biological control

Biological control involves the use of living organisms to combat pests; this generally means manipulation of the insect's natural enemies by man. Biological enemies of insects include parasitic and predaceous insects, mites, nematodes, and diseases; they also include birds and small mammals. Biological control is appealing because when successful it is inexpensive, generally effective over a long period, and safe to humans and wildlife. Recent progress in the development of biological control techniques for selected forest insect pests is given below.

a. Invertebrate parasites and predators

Continuing research on Dendrosoter protuberans, a recently imported parasite of the smaller European elm bark beetle--the vector of Dutch elm disease--has shown that it can overwinter in the Delaware, Ohio area even though climatic conditions are more severe than in its native France. Field studies revealed that three generations per year could be produced throughout most of the United States. Bark thickness of the tree and synchronization of the parasite and host are two factors which limit the efficiency of Dendrosoter in Ohio.

When a biological control program is considered, it is helpful to understand interactions between the host insect and the proposed biological control agents. Such studies are underway with two species of wasps, Apechthis ontario and Itoplectis 4-cingulatus, which are solitary pupal parasites attacking the spruce budworm and the hemlock looper. Heavy concentrations of the host insects have been shown to present a much more favorable environment for parasite effectiveness and survival than low host densities. Also, a silken covering, cocoon, or a facsimile thereof over the host increased parasite survival by 63 percent for A. ontario and 38 percent for

I. 4-cingulatus. Further studies on parasite behavior will help to determine whether competition between different kinds of parasites will be a detriment to natural control--a problem which is basic in a program of importation and colonization of beneficial insects.

Trichogramma minutum, an egg parasite of numerous forest pests, is considered potentially the most important enemy of tip moth eggs in the Southeast; significant egg reduction could occur under favorable conditions. This parasite also attacked 90 percent of the egg masses of the large aspen tortrix collected in Alaska; up to one third of the eggs in the masses were found to be parasitized.

Establishment of Agathis pumila, a parasite of larch casebearer, in its new Western environment in Idaho is definitely assured. From 200 mated females released in one area in 1960 parasitization increased to 17 percent by 1966. Anticipated success of the parasite prompted large scale rearings resulting in 300,000 specimens which have been released in 52 locations throughout the casebearer infestation.

In the last 10 years, 23 species of insect predators, totaling some 65,500 specimens, have been introduced into the Pacific Northwest to control the balsam woolly aphid. The predators were imported from India, Pakistan, Japan, Austria, Sweden, Germany, and Czechoslovakia. Three species of flies and two species of beetles have become successfully established. All prey on the aphid but so far have not reduced populations sufficiently to prevent tree-killing. Aphidecta obliterata was introduced into North Carolina from Germany in 1960 to aid in control of the balsam woolly aphid which has killed more than 2-½ million Fraser fir trees in the Mt. Mitchell area. The beetle has been recovered each year since its release, except in 1961, and appears to be established. Native predators of the balsam woolly aphid were found to be ineffective in reducing aphid populations on Fraser fir in the Mt. Mitchell area.

Extensive observations on natural enemies of fir and spruce aphids in India and Pakistan centered on 5 undescribed species of aphids, Pineus and a new Adelges. Predators representing four genera of beetles were also investigated.

Three new species of mites were found associated with the pales weevil in the Southeast. Some closely related species are considered to be insect parasites; others are sometimes predaceous on bark beetle eggs.

Considerable progress has recently been made on nematodes that are parasites and predators of bark beetles. In New Mexico, two new species of internal nematodes were recovered from the bark beetle Dendroctonus adjunctus. These

parasites have a life cycle well synchronized with their hosts. The nematode Parasitaphelenchus dendroctoni, also an internal parasite of D. adjunctus, was once a free-living form which has only recently become parasitic. Four other nematodes in the genus Mikoletzkya are associated with bark beetles and are suspected as predators on the immature stages of the beetles.

Studies on Contortylenchus reversus, a parasitic nematode of several bark beetles, revealed that egg production of infected host females is reduced by nearly one-half. These nematodes may also be an important cause of larval mortality because they have been recovered abundantly from the larval galleries and are known to readily attack the larvae in the laboratory.

b. Vertebrate predators. Woodpeckers appear to be the key natural control agents of the Engelmann spruce beetle. In an area having an endemic population of Engelmann spruce beetles, 3.1 birds were present per 100 acres the first year of study and 2.2 birds the second year. The diet of 24 northern three-toed woodpeckers was found to consist largely of roundheaded borers and bark beetles, accounting for almost 80 percent of their food supply. Aggregation of the woodpeckers in an area of high food source may be as many as 270 per 100 acres. The major problem in managing woodpecker populations is to determine how to provide the birds with a supply of non-injurious bark beetles and borers between outbreaks.

c. Insect pathogens. The experimental application of a nuclear-polyhedrosis virus and Bacillus thuringiensis by helicopter resulted in a high rate of infection of colonies of the Great Basin tent caterpillar (Malacosoma fragile incurva). Populations were 95 percent lower in the sprayed area than in the unsprayed area the year following treatment. The studies were conducted at Sabino Canyon, a highly used recreational area outside Tucson, Arizona. This is significant in that the use of microbial agents might be a good alternative in recreational and other areas where use of chemical insecticides is undesirable.

Helicopter spraying with 1 gallon of Thuricide 90-T (commercial Bacillus thuringiensis preparation) plus 1 gallon of water per acre in the Pacific Northwest resulted in some kill of the western hemlock looper, but less than needed for economic control. Needs for effective control are an improved Bacillus formulation, more thorough distribution of the spray, and an increased application rate.

A heat-stable exotoxin of Bacillus thuringiensis was found to be detrimental when injected into sixth-instar armyworms. The toxin either killed the larvae before they completed pupation, or it caused a delay in pupation and the occurrence of abnormal pupae. Changes in blood volume also occurred. Work needs to be done to determine the makeup of the toxin.

In Connecticut an unusual bacterium, a species of Proteus new to science, was isolated from living and dead gypsy moth larvae. This new bacterium possesses a unique feature of extracellular slime production, and also has biochemical characteristics that differ markedly from described species of Proteus.

At Corvallis, Oregon, pilot-scale production methods were developed in cooperation with private industry for a nuclear polyhedrosis virus of the Douglas-fir tussock moth. Production costs were high but it is believed that large-scale production can lower costs to an acceptable level. In addition, procedures were developed for quality control of industrial batches of virus. Water-base formulations for virus sprays were developed which appear to be far superior to any used previously. These formulations are rainfast, compatible with virus and host insect, and maintain the pathogen in suspension.

Several electron microscopy techniques for studying diseases of forest insects were developed. These include: (a) a standard procedure for glutaraldehyde fixation of insect blood cells--this has worked well on several species of caterpillars, (b) a glutaraldehyde procedure for fixing polyhedra and virus capsules, and (c) a dissolution procedure for single and multiple-rod polyhedra--this procedure can be used for routine checking of bulk specimens.

A survey initiated to determine the microorganisms associated with the southern pine beetle has turned up 16 species of fungi from the exterior of the beetles, 5 of which have been shown to be possible pathogens. Eight other species have been found in the body cavity, 6 of which are known pathogens.

2. Chemical control

While non-chemical methods hold promise for the future, chemical control remains in most instances the most potent and reliable weapon in the present fight against destructive forest insects. Forest Service research attempts to develop better and cheaper control methods and ones that are safer to humans and wildlife. It searches for materials that have "host-specificity", that is, insecticides toxic only to the target insect. When possible it seeks insecticides that are effective without reliance on extended residual action. Recent research progress on the chemical control of several forest insects is given below.

Nearly 40 insecticides were tested in the laboratory against the spruce budworm in 1966. The 10 most toxic compounds were: pyrethrins, Zectran, mevinphos, Dursban, dichlorvos, GC 6506, S 4084, parathion, Matacil, and

Imidan. All of these compounds and several others were more toxic than DDT. Attempts to synergize Zectran with 21 different compounds failed. Zectran as a spray is only slightly more toxic to the second, third, and fourth instars than to the fifth and sixth instars and pupae. It is about 10 times more toxic topically than when administered in an artificial diet.

By means of a fluorescent tracer technique, it was found that the drop sizes most effective against the budworm were those under 50 microns mass-median diameter. This finding has led to a new type of aerosol treatment with Zectran that will be pilot tested in 1967.

Diatomaceous earth was also found to have some insecticidal properties on the spruce budworm. The reduction in populations on treated trees, however, was not great enough to provide satisfactory control, and furthermore the rate of application used (up to 55 pounds per acre) would be prohibitively expensive to distribute by aircraft.

In Michigan, a pilot insecticide test was directed against the jack pine budworm. Malathion low-volume concentrate was applied by air at the rate of 13 fluid ounces per acre. Results showed an average population reduction of 76 percent when counts were corrected for population changes in the untreated plots. This compares favorably with malathion high-volume applications used in the past.

Additional studies in the Lake States have shown that the Saratoga spittlebug can be controlled in the nymphal stage with chemicals. This insect is normally controlled in the adult stage with DDT or malathion. A pilot test revealed that spittlebug nymphs were eliminated from 30 test plots following the application of granular Baygon at the rate of 3 lbs. per acre. This is particularly important because the timing for control of the nymphs is far less critical than the timing for the adults.

In the Southeast, field experiments with the systemic insecticide Bidrin, injected into 80-foot-tall slash pine seed production trees in early May 1966, reduced attacks by Dioryctria coneworms and the slash pine seedworm by 93 and 99 percent, respectively, during the final 4½ months of cone development. This approach shows promise for reducing the number of insecticide applications, lowering costs, and eliminating the need for precise timing of sprays.

The pine needle-sheath miner in California was effectively controlled by a water emulsion spray (of malathion) applied by helicopter at the rate of 1 lb. of insecticide in 25 gallons of water. Numbers of insects were reduced by nearly 99 percent 24 hours after treatment.

Studies on the movements of systemic insecticides within plant tissues were continued in the southeastern States in 1966. Both Bidrin and Thimet were tested on loblolly pine seedlings. The largest amounts of Bidrin were found in the needles and the xylem one day after treatment. Fifteen and thirty days after treatment Bidrin was still largely detected in the needles but the phloem and cambium contained greater amounts than the xylem. This indicates lateral diffusion of the Bidrin from the xylem into the phloem and cambium or a downward translocation of the material from the needles. The results using Thimet under the same experimental conditions were similar. In addition a single treatment of Thimet has protected seedlings for over one year against aphids and the pales weevil.

Systemic insecticides continue to show good promise for controlling the cottonwood twig borer and associated borers and defoliators in the South. However the toxicity hazards of these chemicals are such that they require safer application methods for their wide acceptance and use. Limitations in availability of the Phorate formulation used for cutting dip applications spurred a search for a suitable substitute. The material NIA 10242 tested in 1966 showed promise as a cutting dip dust and in granular applications, but further experimentation is needed. Previous tests showed that cottonwood trees protected from insect damage during their first 3 years contained an average of nearly three more 4-foot pulpwood bolts than unprotected trees on the same site. This amounts to more than 5 cords per acre and reflects the superior form and merchantable length of the protected trees.

The Texas leaf-cutting ant is a serious economic pest in the upland forests of east Texas and west central Louisiana. Regeneration of pine is impossible in some cases without thorough control of the colonies for several years. A bait containing Mirex, a slow-acting stomach poison that has been used successfully for controlling the imported fire ant, will stop foraging activity within five days and destroy the colony within 30 days. Mirex is a surer method of control than fumigation, and it can be applied year long, is safer, and cheaper.

In Spain, a PL-480 study was completed on the control of several poplar borers including Cryptorynchus lapathi, Saperda carcharias, Gypsonoma aceriana, Melanophila picta, and Saperda populnea. Nursery fumigation schedules with methyl bromide were developed. Larvae of borers in galleries were controlled by using insecticide-impregnated cotton plugs in gallery entrances.

3. Other control methods - Male sterilization, tree resistance, site and stand manipulation, attractants.

Silvicultural control or control through stand manipulation has long been practiced in some areas against some pests and still holds promise for others. Tree resistance is another approach that will become increasingly useful as management becomes more intensive and additional knowledge is gained about resistance mechanisms. There is much interest in the sterile male technique, which uses the insects themselves to effect their own destruction. Sterilization is attempted either through the use of ionizing radiation or chemicals. Another rapidly developing field of insect control is concerned with sex attractants. These materials, known technically as "pheromones", attract insects of one sex to the other. When isolated, chemically identified, and synthesized, they can be used to lure insects into places where they can do no damage or where they can be readily destroyed. Recent advances in these various non-chemical approaches toward insect control are presented below.

Five chemosterilants were evaluated against male spruce budworm pupae in 1966. Tepa and metepa showed promise in arresting reproduction by more than 99 percent, but tretamine, apholate, and hempa were not as effective. Metepa-treated males reduced egg production as well as percent hatch when mated to normal female moths. The most effective time for treatment of the males is during the first 24 hours after pupation.

Previous studies had revealed that the male carpenterworm moth could be sterilized by topical applications of tepa. Further work on this indicated that males could be sterilized by contacting a residue of tepa. Since a potent sex attraction has been demonstrated, it may be that the sex pheromone can be used to lure male moths to a residue of tepa where they can be sterilized upon contact.

Host resistance studies indicated the mountain pine beetle was unable to successfully attack the Jeffrey x Coulter pine hybrid in mass forced attacks tests. This hybrid has now demonstrated resistance to the pine reproduction weevil and the western and mountain pine beetle.

Current studies showed that certain individual slash pines are inherently resistant, while others are susceptible to cone and stem attacks by Dioryctria spp. coneworms. Also it is now known that tip moths, Rhyacionia spp., lay eggs indiscriminately on all southern pine species. Differential host injury however is considered to be a result of the effects of oleoresin on the feeding larvae.

Ponderosa pines planted in Michigan have been found to be about one-half as susceptible as local red pine to attacks by ovipositing females of the European pine sawfly. Of three seed sources tested, one from the Deschutes National Forest was significantly underattacked and considered highly

resistant to the sawfly. This seed source could prove important to tree breeders should this sawfly become established in the West where ponderosa pine grows naturally.

Prescribed burning to control the red pine cone beetle, (which overwinters on the ground) reduced the percentage of attacked cones in Lake States seed-production areas. After burning, the average percentages of beetle-infested cones were: 2 percent in the burn center, 6 percent midway between center and edge of burn, and 35 percent outside the burn. Losses of cones to the moth Eucosma monitorana, a lesser pest, were also significantly reduced in burned areas because this insect spends roughly the same period in the litter and responds similarly to the fire treatment. Damage by another moth, Dioryctria disclusa, increased when the fire treatment eliminated its competitors, but not enough to jeopardize the value of the treatment.

Results of sex attractant studies of male European pine shoot moths in the Pacific Northwest were disappointing. Moths tagged with fluorescent dust were released at prescribed distances from traps containing female attractants. The longest directed response flight occurring during an evening flight period was just under 100 yards. In several experiments of this type, only 10 to 36 percent of released males (those capable of flight) responded to the traps.

Sex attractant studies on sawflies continued in Wisconsin. Some 19,000 female sawflies were used to collect the attractive material. The chemical was purified and analyzed, and some 30 candidate compounds in the molecular weight range of the material have been synthesized. Similarly, about 8500 female white fir sawflies were collected for attractant studies. Field studies indicate that the sex attractant compounds do not volatilize over great distances. This suggests that male sawflies must be close to females before they respond to the attractant.

4. Biology and ecology

a. Bark beetles. In 1966, the Forest Service concentrated southern pine beetle research at Alexandria, Louisiana. Results from studies established previously show that seasonal fluctuations and attack patterns of the beetles under low population conditions in Louisiana vary in much the same way as do epidemic populations in east Texas. The number and size of new infestations increase most rapidly during April, May, and June, but populations decline suddenly in the late summer. Each fall, however, beetle populations begin to increase.

Emphasis has been placed on identifying the many species of mites associated with the southern pine beetle and evaluating their usefulness. So far almost 100 species, many of them new to science, have been found. Eight

species are known to be predaceous upon various life stages of the beetle. A biological study of a common species of Pygmephorus is nearing completion. Although close relatives of this mite are known to be predaceous, indications are that this species feeds upon breakdown products of fungi and yeasts in beetle tunnels.

Lightning-struck trees have been found to serve as focal points for southern pine beetle outbreaks and, during periods when beetle activity was limited, the insects usually occurred only in these trees. This association of beetle attack with lightning strikes was most evident in July and August 1966 when 75 percent of spot infestations examined contained at least one lightning-damaged tree. Comparisons of brood development showed that beetle attacks occurred first on these trees, then on adjacent ones. Lightning-struck trees were also shown to be extremely attractive to the western pine beetle in the Western States.

In genetics tests, the four possible mating combinations of the Douglas-fir beetle from coastal and interior sources all produced fertile progeny. However, the number of progeny differed significantly between crosses, and sources of trees used for the tests. Tests of populations that may be more genetically isolated, and of closely related species are proposed to determine if sterility can be induced in wild populations.

In studies of the mountain pine beetle in Utah, both the length of egg gallery and the number of eggs the female deposits per inch of gallery are related to the proximity of other galleries. These two relationships strikingly affect competition for food within the immediate brood and those adjacent to it. Here the use of the individual gallery as a sampling unit has biological meaning and permits an accurate assessment of relationships. The use of a biological unit may result in more accurate data and, hence, more meaningful conclusions drawn from studies of factors affecting populations than sampling schemes based on area sampling. This would in turn make possible more accurate biological appraisals of insect outbreaks.

Studies of the mountain pine beetle in young ponderosa pine stands in the Northwest have shown that overstocking is commonly associated with outbreaks. The first significant infestation usually occurs when stands are 55 to 65 years old. In unmanaged stands, infestations are likely to recur at intervals of about 20 to 40 years. In relation to their abundance in the stand, dominant and co-dominant trees are more likely to be killed than are suppressed or intermediate trees.

Ips pini frequently is an important cause of tree mortality in recently thinned stands of ponderosa pine in Oregon and Washington, particularly where thinnings are made in the spring and early summer. Consequently, forest managers have generally scheduled thinning operations in the late summer, fall, and winter. However recent rapid expansion of thinning

programs has created the need to thin year-round. Most ips-caused mortality seems to occur in stands that are stagnated or approaching stagnation when thinned. This observation means that (1) restricting thinnings to certain periods of the year may be necessary only in stagnated stands, and (2) thinning can be done safely throughout the year in non-stagnated stands.

Further information was obtained on different aspects of attraction of trees to the Black Hills beetle in the central Rocky Mountains. Field tests in 1966 demonstrated that: (1) the forced attack must be accurately coordinated with the natural emergence of the wild population; (2) trees of low vigor should be used as trap trees to avoid pitch out and an unsuccessful release of attractant; and (3) the cages should be recharged with new beetles if fine boring dust is not produced. Bolts infested in the laboratory and fastened to green trees have also been effective attractants.

In the northern Rocky Mountains during July and August, adult pine engraver beetles were found congregating at the base of trees that had the inner bark destroyed by the mining of attacking beetles. Heretofore the only period during which beetles were found congregating in the region of the root collar was late September or October in preparation for overwintering. If this congregating during the summer months is widespread and consistent, it may have important control implications.

The life history of Ips lecontei, a pest of ponderosa pine in Arizona, has now been worked out and it is known for the first time that there is a spring, early summer, and late summer brood each year. The adults of the early summer brood are extremely aggressive, attacking apparently healthy trees in groups containing up to 200 trees. Logging debris, where high populations build up rapidly from mid-April through July, is especially attractive to Ips lecontei. This is reflected in the presence of large groups of attacked trees throughout areas of summer logging. Summer-created slash over 3 inches in diameter should be disposed of immediately by burning or it should be made unfavorable to the beetles by spraying with an insecticide.

Cold hardiness studies of the overwintering adult stages of two species of five-spined Ips were made during the winters of 1960-61 and 1961-62. Ips confusus infesting pinyon in Arizona and New Mexico can successfully withstand 5° to 10° F. colder temperatures than Ips lecontei. Little if any cold hardening was exhibited by either beetle between November and March, but both beetles tolerated colder temperatures the second year. Mortality varied with air temperature, length of exposure, bolt diameter, and bark thickness. Natural mortality in the infested forests verified the accuracy of the laboratory experiments. Ips lecontei suffered complete mortality when 5- to 6-inch diameter bolts infested with the insect were exposed to -10°F. temperature for a period of 3 hours. Under the same conditions, 80 percent of Ips confusus were destroyed.

Research in Missouri has shown that oak bark beetles meet some of the basic requirements of a vector for the oak wilt fungus. The beetles often make successful breeding attacks on oak wilt trees before internal symptoms appear. Following these attacks the parent adults reemerge. Since unsuccessful breeding attacks have been found to be very common on apparently healthy oaks, it appears that the parent adult beetles from oak wilt trees may be attacking healthy trees. If this is so they could be transmitting the oak wilt fungus. Preliminary studies indicate that a higher percentage of reemerging parent adults carry the fungus than do the young adults when they emerge from a diseased tree; only females carry the fungus. In addition, much of the biology of the oak bark beetle has been worked out which will help understand the relationships between the insect and the fungus.

b. Defoliators. In order to evaluate various factors that may contribute to natural mortality of the spruce budworm in the central Rocky Mountains, mortality due to known causes has been studied by age intervals. It was learned that survival of the budworm through the first age interval, (i.e. from eggs through instar III) is the one most closely correlated with survival of the entire generation. The specific determining factors within these age intervals will now have to be identified.

Predictions of trends in budworm infestation from year to year are based upon the changes in the density of new egg masses on foliage samples. Examination of foliage is the major cost of the survey. Heretofore the conventional sample unit has been a half-branch from the midcrown. Results of sampling studies have now shown that a smaller, 24-inch branch sample gives an equally satisfactory estimate at considerably less cost.

Data collected in spruce budworm egg surveys in the Pacific Northwest over a four-year period were analyzed to compare trends based on two different sampling methods. One was the standard approach of comparing density of new egg masses on foliage from year to year. The second method used old egg masses found in the current year to represent the previous year's egg population. Results showed that reliable trends can be obtained with only one year's sampling, using old egg masses to represent the previous year's new egg masses. This will also reduce the cost of predicting trends.

In southeast Alaska western hemlock is more severely damaged than Sitka spruce during black-headed budworm epidemics despite the fact that the budworm will feed readily on both species. Budworms prefer western hemlock foliage over Sitka spruce for oviposition, but during prolonged outbreaks, when hemlock is severely defoliated, budworms may be forced to lay eggs on spruce. However, elongating spruce shoots do not provide as much shelter for young larvae as do hemlock buds, thus increasing larval mortality. Silvicultural practices favoring spruce over hemlock would probably reduce budworm damage.

Two population declines of the black-headed budworm have occurred in the last 25 years. From a study of weather records for southeast Alaska for the period 1945 to 1965 it now appears that the collapse of high budworm populations occurred in years of unusually warm, dry weather during July. Actual cause of budworm larval mortality is unknown, but high temperatures during the larval period are suspected.

Lodgepole needle miner studies were conducted in California to determine the cause of the recent sharp decline in the needle miner population, the current status of the population, and the impact of the miner on the host. The sharp decline was associated with adverse weather when the new generation of insects was getting established in midsummer. At the reduced population level, mortality caused by eulophids, primary parasites of leaf miners, is proportionately higher than in the epidemic population. Impact, as measured by tree mortality and by reduction in foliage, shoot, and annual ring growth, is most severe in older trees. Death of a tree often follows when annual ring width falls below 0.4 mm. However surviving trees recover rapidly when released from the infestation by spray or by natural population decline.

Studies in 1966 on the red fir needle miner confirmed previous evidence of a 2-year life cycle and overlapping generations. No serious impact to red fir was indicated. This 2-year life cycle in red fir in California is in contrast to the 1-year cycle in Utah in white fir. Infestations continued but were lighter than in 1965.

Research on the Great Basin tent caterpillar revealed that it has only one generation per year, and that 22 species of parasites prey upon it at different stages in its life. Repeated defoliation of aspen by this insect reduces radial growth of trees an average of 75 percent in stands heavily defoliated for 3 consecutive years.

Defoliation resulting from an outbreak of the pine butterfly in ponderosa pine in central Idaho in 1952-54 was shown to have caused 39 percent growth reduction. The annual growth loss was estimated to average 72 board feet per acre. Tree mortality caused by this epidemic was 1.3 percent of the stand, or 0.6 percent of the volume. Losses in an infestation that occurred in 1922-23 were 26 percent of the stand and 36 percent of the volume respectively. The comparatively small losses in 1952-54 are the result of aerial spraying treatment that suppressed the outbreak.

The larch casebearer has killed few trees in the Rocky Mountains, despite 10 years of severe defoliation. However radial growth has been greatly reduced; measurements showed a 55 percent reduction during the 6-year period 1957-1962.

c. Borers and tip feeding insects - Population dynamics studies of the pine root collar weevil suggest that adult populations can be reduced. Pruning off the bottom 3-4 whorls of branches and removing the accumulated duff increases heat and light at the base of the tree beyond tolerance of the adults. Behavioral studies indicated four new chemical suppression techniques. These are: (1) spray the trees with a contact insecticide, (2) apply a granular insecticide between trees, (3) apply a systemic insecticide to the foliage, or (4) apply heavy dosages of chemicals to the base of "occasional" trap trees.

A monograph has been written on the weevil genus Curculio which gives the taxonomic positions, morphological descriptions, biologies, and geographic distributions of the twenty-seven species in the United States and Canada. It summarizes information in such a way that workers can accurately associate weevil species with host tree species, weevil numbers with seed losses and weevil species with their respective natural control factors.

On the basis of behavior, Pissodes strobi and P. approximatus that infest white pine appear to be distinct species. Yet they can not be readily separated morphologically by conventional taxonomic methods. Hybridization studies so far suggest there are no absolute sexual isolating mechanisms. Apparently other factors such as seasonal or habitat isolation, hybrid vitality and/or sterility, or some other factors must be operating under natural conditions to prevent free intermix of these two species. P. nemorensis is also considered a valid species and distinct from P. strobi and P. approximatus. Positive identification is absolutely essential for successful control of any pest species. Lacking this, control can be both ineffectual and wasteful.

In Mississippi, a study of carpenterworm gallery construction revealed that larvae feeding initially in the inner bark and cambium start tunneling into the sapwood as early as one month after hatching. They cut crooked galleries obliquely upward into the sapwood for about 4 months, then turn vertically upward. The rapid trunk penetration and the construction of extremely crooked galleries during early larval activity complicate the development of practical direct control measures and also provide effective protection against predaceous birds and insects.

The fir tree borer, found in the coniferous forest belt of North America, causes serious degrade in lumber manufactured from windthrown white fir. Its habits and life history were studied for 3 years in California, following a disastrous windstorm in 1962. Adult borers attack in early spring, laying eggs in bark crevices. The larvae excavate winding galleries in the phloem, deeply etching the sapwood. Damage is caused when the larvae then bore up to 3 inches into the wood to construct pupal chambers. Three

principal natural enemies were found, two predators--woodpeckers and an ostomid beetle--and a braconid parasite. Population fluctuations hinged primarily on availability of host material and pressure from natural enemies.

Results in eastern Kentucky plots over the last 6 years indicate that the red oak borer can be controlled through stand manipulation. Examination of stands left after logging disclosed that slower growing trees are most preferred by the borer. Results based on three complete generations of the borer over six calendar years clearly showed that the incidence of borer attack decreases as annual diameter growth increases, regardless of tree diameter class. Thinning operations during the second (non-attack) year of the red oak borer's life cycle have produced the following results: (a) thinning reduced the number of susceptible stems present for attack; (b) Increased vigor induced by release is expected to reduce the number of successful beetle attacks as soon as the trees began growing at a more rapid rate; and eventually (c) as the stand begins to stagnate, a return to pretreatment borer population levels would be expected.

d. Wood products insects - There has been concern regarding the use of persistent chemicals for prevention of termite attacks because of the possibility of contaminating wells and streams. In seven major soil types, water emulsions of the insecticides were applied to the soil surface at the rate of 1 pint per square foot. After six years over 67 percent of chemical remained in the top inch of soil and in most cases less than 1 percent was found 4-3/4 inches below the surface. Furthermore neither bioassays nor chemical analyses have shown any insecticide present in a spring and a swamp downgrade from large termite control plots established in Mississippi 1956 and 1958. These two studies indicate that there is no significant insecticide movement through the soils studied, and that there appears to be little danger of contamination of wells and streams by them.

Untreated lumber of most commercial species is susceptible to termite damage, especially when in contact with the soil. A study involving a combination of wood, plastic and irradiation treatment, revealed after 10 months exposure to termites in Mississippi that monomers of the plastics methyl methacrylate and methacrylic acidmethyl methacrylate solution impregnated into the wood and irradiated with cobalt 60 made the wood somewhat resistant to termite attack. Further study is necessary to determine whether these treatments will give the long-term protection required of an acceptable wood preservative.

A gland known to secrete an attractant which enables termites to follow trails made by other termites has recently been investigated. So far the exact role of the attractant in termite ecology is unknown, but if it is used to lead termites to or locate a food source it may possibly be utilized

in control measures. Studies are in progress to chemically identify the secretion.

e. Sucking insects - Intensive studies were started in 1966 to gain an understanding of the ecology of the balsam woolly aphid. This insect is an introduced pest and probably the most serious enemy of true firs in the Pacific Northwest.

An abnormally large amount of ray tissue is one characteristic of wood produced in North American firs infested by the balsam woolly aphid. The presence of abnormal ray tissue is significant because it tells something of the fundamental host reaction to the aphid. An increase in ray tissue materially affects the structural quality of the wood, and rays preempt space that would otherwise be occupied by water-conducting tracheids. Investigation of three species of western true firs (grand, subalpine, and Pacific silver) showed that wood from aphid-infested trees had 35 to 73 percent more rays per square millimeter of tangential surface than normal wood.

Dispersal studies of the tuliptree scale suggest that air movement is the primary factor in dispersal between trees over distances of up to 150 feet. Maximum dispersal was obtained with wind velocities of up to 7 mph. and at 68°F. Scale infestations depend on the orientation of potential hosts in relation to source of crawlers, distance to the source, and the presence of intervening vegetation. Damage studies showed that, during the months of July and August the average quantity of scale-produced honeydew was 6 milligrams of dry sugars per scale per day. Since scale populations on 8 ft. yellow-poplars commonly range from 500 to 3,000 individuals per tree, this drain on nutrient sugars is largely responsible for the dead, distorted, and poor vigor yellow-poplars in study areas.

The ant Dolichoderus taschenbergi, which feeds on honeydew excretions of the tuliptree scale, has been found suppressing the natural enemies of the scale in the northeast. Ants from one nest will forage a territory of about 0.6 of an acre. There are as many as 30 ant nests in a 24-acre old field site. The activities of this species of ant are confined to open sites; such sites remain open longer than non-infested sites due to the protection of the scale which suppresses yellow-poplar regeneration.

f. Seed and cone and miscellaneous insects - The 18 red pine seed-production areas in the North Central States continue to produce seed crops inadequate to meet the needs of National Forests. Losses due to insects contribute significantly to the problem. In samples received this year from 10 of the 18 seed-production areas, 56 percent of second-year cones were damaged by insects. Two species, Conophthorus resinosae and Dioryctria disclusa, destroyed 41 percent of the cones.

In the Southeast, the possibility that slash pine possesses inherent resistance to infestation by Laspeyresia anaranjada was discovered by following cone infestation on individual trees over a three-year period. Clonal tests with propagules from these trees are needed to determine whether or not resistance to this insect is inherited.

Flight and mating activities of the cone moth Dioryctria abietella were investigated in the Southeast. Photographs taken at 30-minute intervals indicate that peak mating and flight activities coincide in time, occurring 8 to 10 hours after onset of darkness. These activities begin to decrease after about 11 hours and cease at the onset of light.

Studies on the European pine shoot moth in Washington and Oregon showed that 10 to 20 percent of released males were capable of finding small mugho pines. This occurred even during cool wet weather. A technique for mating European pine shoot moth in the laboratory was greatly improved; it will expedite development of sterilization techniques. The new method resulted in about 60 percent of the females being mated compared with a maximum of 36 percent in the previous method. The new method also requires less handling of insects.

PL-480 studies in Colombia, Uruguay, and Brazil, underway now for 5 years, have yet to indicate any native pest causing serious damage to introduced North American pines. About the only serious insect pest observed so far is the European pine shootmoth, Rhyacionia buoliana in Uruguay; presumably it was introduced from Europe many years ago.

5. Insect physiology

Studies in insect physiology fill important gaps in understanding basic relationships between different insects and between insects and their hosts. Presented below are a few highlights of physiological research results obtained in the past year.

Preliminary pharmacodynamic studies on single heart muscle cells in the cockroach are yielding some interesting information of the effects of various drugs, particularly bromolysergic acid diethylamide. The excised heart of Periplaneta americana reacts strongly to the presence of minute quantities of this drug, which stops heart action almost instantly. Such information may be useful not only in elucidating the physiology of insect nerve and muscle, but also in future insecticide development.

Interest in the identity of possible neuromuscular "transmitter" substances has been intensified by a recent report that curare in low dosages can produce a more or less complete paralysis in a number of insect orders.

An attempt was made to paralyze tobacco worm larvae by injection of high concentrations of d-tubocurarine, but without success. On the other hand, injections of an experimental compound (RT 952) at levels of about one microgram per milligram body weight quickly produce complete paralysis in this organism. This finding has broad fundamental implications in insect neurophysiology and will be followed up on other insects. This compound may also be of toxicological interest as it opens the possibility, both chemically and physiologically, of a new family of insecticides.

Electroantennogram studies of the cone moth indicate that two or more chemostimulants from slash pine conelets are affecting the moth's behavior--an attractant and an olfactant influencing oviposition.

Paired fungal tubes, or mycangia, open at the base of the front legs of the female southern pine beetle and contain fungi that probably are associated with beetle nutrition. Sectioning and staining of the mycangia from emerging beetles have revealed yeast-like spores of 2 sizes. Both sizes were not present in the same beetle. Sectioning of young soft bodied adults has disclosed well developed mycangia, but no organisms within them. Preliminary investigation of a fluid within the mycangia indicated an antifungal characteristic.

6. Insect rearing methods

Laboratory rearing of insects is necessary for many kinds of research. Controlled laboratory studies, such as those utilizing insects for bioassay, require large numbers of healthy, vigorous, even-aged insects. Many nutritional studies require feeding insects on artificial media so that great or slight changes can be controlled in their diets. Knowledge from such studies is fundamental to those concerned with problems involved with pesticides, host selection, sterilization, behavior, sex attraction, and others. Recent progress or rearing techniques for several forest insects is given below.

Two artificial media developed in the Pacific Northwest for the Douglas-fir beetle permitted 75 and 42 percent of newly hatched larvae to develop to the adult stage. Immature beetles appear tolerant of considerable variation in pH and physical consistency and palatability of food material but are relatively sensitive to moisture levels. Adults appeared normal, and females were capable of laying viable eggs. These two media are now being used to bioassay inner bark food material from different host trees to determine whether or not there are fundamental nutritional differences between them.

Two ground phloem media have been developed for rearing the oak bark beetles Pseudopityophthorus pruinosus and P. minutissimus. Larval survival averaged 88.1 percent with microbial inhibitors; without microbial inhibitors survival averaged 78.4 percent. Further, a larval diet for the smaller European elm bark beetle has been developed. Newly hatched larvae placed in the diet develop as rapidly as those in elm wood and average slightly larger. Approximately 80 percent of the larvae placed on the diet develop into adults.

A ground phloem medium developed for rearing immature bark beetles in California is being used in studies of diseases, nutrition, and microorganisms.

In the past the carpenterworm has been reared in sizeable numbers in cages on the trunks of host trees. Recent laboratory studies indicate the insect will develop on a simple diet of raw apple. If survival proves good, this diet will be used instead of a more complicated one.

A method has been developed in California for rearing western spruce budworm on an artificial diet. It largely follows the procedures used in Canada to rear the eastern form of the budworm. Mating success, fecundity, and larval and pupal survival are similar to those obtained in Canada. Some cultures are in the fourth generation and there has been no apparent effect on vitality. About 3,000 larvae are being reared weekly with this method.

A new complex artificial diet has shown promise for rearing the mimosa webworm. The diet, containing a small amount of fresh leaves for a feeding stimulant, assures development into normal sized adults. A slightly improved diet and suitable technique for rearing large numbers of the moths are now being investigated.

7. Survey and sampling techniques.

Decisions by wildland managers about forest insect control programs should be made from a sound biological evaluation of the present status and probable future trend of populations. Evaluation requires determination of the amount of loss, the level of the pest insect population, the extent to which the natural mortality factors are present, and other predictive information. Survey and sampling procedures are used to estimate these components.

In 1966 a computer program was developed in the Lake States for simulating insect survival and abundance over any number of generations. Different patterns and intensities of survival can be specified to simulate changes in numbers of different species of insect pests. It provides a gross experimental means of exploring on the computer the effects of actual or potential pest control methods before they are applied in the field. It can suggest

what degree of long-term control is needed to reduce populations any given amount, and where the best point is in a particular life cycle for applying a given degree of control to achieve maximum population reduction.

Studies in 1966 in the Pacific Northwest revealed that Douglas-fir tussock moth populations can be reliably estimated by sampling branches. For equivalent precision a much larger sample is needed for eggs than for larvae Larvae are not uniformly distributed over the tree but the middle crown appears to be representative of the whole tree. Sequential sampling plans for both eggs and larvae were prepared in 1966 which will be adequate for general classification of population size or trend.

Studies are underway involving attraction of male to female European pine shoot moths as a potential survey tool and possibly for control purposes. In 1966, procedures to improve present trapping technique by prolonging the period of attraction were tested. Ethylene or propylene glycol was blended with standard solvents containing the attractant. Traps baited with 10 female equivalents and containing a glycol additive remained attractive for 13 days during cool, wet weather, compared to only 6 days for those lacking this additive. During a warmer period when the evaporation rate was undoubtedly higher, baits containing glycols remained attractive for 6 days compared to an average of 3 days for those without the additive.

In California significant progress was made in each of the following areas of research for which the usefulness of aerial photography and other remote sensing imagery is being investigated: (1) the development of image specifications for the detection of insect and disease attacks on forest trees; (2) the aerial photo identification of commercially important tree species; and (3) the inventory of forage, livestock, water, soil and recreational resources of wildland areas by means of multispectral remote sensing.

Ultraviolet (blacklight) light traps of an improved design provided basic information in 1966 on the seasonal activity and relative abundance of seed-destroying insects in the South. This information will be used to improve insecticide spray schedules for seed orchards. As a result of this research, blacklight traps are also being employed as a detection method for evaluating the species composition and geographic distribution of destructive insects in seed orchards throughout the South.

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C. FOREST DISEASES

Problem

All forest tree species, hardwoods and conifers alike, are subject to disease. This is true in all parts of the country irrespective of land ownership, and for trees of all ages from the seeds themselves to overmature forest veterans. Diseases affect all parts of the tree from the root tip to the terminal bud and from the outer bark to the central pith. Forest plants important to forage, recreational, and watershed values are as subject to attack as those in commercial forests. Tree diseases are caused by biotic agents such as flowering plants, fungi, bacteria, nematodes, and viruses; and by abiotic factors such as temperature and moisture extremes, nutritional excesses or deficiencies, and noxious substances in the atmosphere. Working singly or in combination, diseases cause death, loss of growth, deformity, lowered quality, or destruction of wood already formed in forest trees. In total, they cause as much loss in our forests as all other destructive agents combined, including fire, insects, and animals. The impact of diseases on growth is estimated to amount annually to 5 billion cubic feet, including 20 billion board feet of sawtimber. In addition, disease agents reduce the value of wood products in use by an estimated $300 million per year.

USDA and Cooperative Programs

The Department has a continuing long-term program of basic and applied research directed toward the solution of forest tree disease problems and the development of means for their control. The program is a national responsibility of the Forest Service and is conducted at all 8 of the Forest Experiment Stations, the Forest Disease Laboratory at Beltsville, Maryland, and the Forest Products Laboratory. Each of the Stations conducts research on a variety of diseases of special importance in its geographic area of responsibility and may also have leadership for research on diseases of broader regional impact. For example, the North Central Station has primary responsibility for research on hypoxylon canker of aspen, the Northeastern Station for oak wilt, the Pacific Northwest for Poria root rot of Douglas-fir, the Intermountain for breeding western white pine for resistance to white pine blister rust, and the Southeastern and Pacific Southwest Stations for research on air pollution in relation to forest tree diseases.

The Forest Service now devotes 76 professional man-years of effort to research in this area and has general supervision over another 26 man-years of foreign professional effort devoted to 11 PL-480 projects abroad. Over one-half of the Forest Service scientists working on tree diseases are plant or forest pathologists, but to provide the talents required to solve our increasingly complex

problems, we now employ biochemists, ecologists, meteorologists, microbiologists, nematologists, physiologists, serologists, and soil scientists.

This research program is carried out in cooperation with other Federal, State, and local public agencies. The Department of Defense and the Department of the Navy both continue to support research on the decay of wood in use; HEW, TVA, and the University of North Carolina cooperate on studies of the effect of air pollutants on trees. The Georgia Forest Research Council provides financial aid, and several State Forestry agencies provide labor, land, and equipment for research on tree diseases. Cooperative aid programs are financed at the University of Hawaii for the studies of seedling diseases; the University of Colorado for the genetics of dwarfmistletoes; Pennsylvania State University to determine the effect of microclimate on the life cycle of Fomes annosus; Oregon State University for the study of the spread and intensification of ponderosa pine dwarfmisletoe; the University of Connecticut for determination of bacteria associated with wood decay organisms; the University of Mississippi School of Medicine for the biochemical characterization of the fungus Lenzites saepiaria; and Texam A&M for study of the causes of live oak decline and mortality in east Texas.

The extramural program for research was continued under Public Law 85-934. In the past year a grant for research was made to Pennsylvania State University for a study of the spore germination and host penetration by heartrotting fungi. Other grant projects being continued under this program are: with the Brooklyn Botanic Garden for the study of the biological effect of root exudates on soil pathogens; with the University of Mississippi Medical center for enzymic and nutritional studies of Cronartium fusiforme; with the University of Wisconsin for research on the nature of resistance in eastern white pine to infection by the blister rust fungus; and with North Carolina State University to work on the biochemistry of wood decay. A grant to Duke University for research on the aerobiology of the fungi of Piedmont forests has terminated this year on completion of the work.

Research projects supplementing and complementing our domestic ones are under way in Taiwan, India, Brazil, Colombia, Uruguay, Italy, Poland, and Yugoslavia. These are conducted under PL-480 authority and funds. They vary in complexity from critical studies of the development of specific fungi to general observations on the health and growth of North American forest trees planted abroad.

Cooperation also extends to industrial forestry organizations through free interchange of research results, cooperative use of forest lands, and technical consultation. As in the past, chemical companies continue to donate promising products for experimental use and many provide technical advisory services on their use.

The annual outside effort by our cooperators is estimated to be equivalent to one-half of the manpower devoted to tree disease research by the Forest Service.

Programs of State Experiment Stations and Schools of Forestry

A total of 28.4 scientist man years is devoted to this area of research.

Progress--USDA and Cooperative Programs

1. Seed and seedling diseases

a. Causal organisms. Microscopic studies of pine seedlings infected with Verticicladiella wagenerii indicate that this fungus causes a vascular wilt type of disease similar to oak wilt or Dutch elm disease rather than a typical root rot disease such as is caused by Fomes annosus or Armillaria mellea. Field observations in California indicate that V. wagenerii is more prevalent than previously suspected. Host range studies reveal that most pines and Douglas-fir are susceptible to this disease.

Fusarium oxysporum, a fungus which causes a root disease of pines has been found in forest nursery soils of California. Since observations indicated its absence from and the probabliity of its introduction into native forest soils, the ability of the fungus to survive in forest soils was tested. Populations of F. oxysporum, when introduced into forest soils or the roots of nursery seedlings, were found to die out over a 3-year period. This suggests that the absence of this pathogen from forest soils is not due to the lack of introduction but to an ecological restriction of forest soil against this fungus.

Greenhouse inoculations in Georgia have confirmed the pathogenicity of Pythium irregulare, P. vexans, and several other Pythium spp. to pine seedlings, both as causes of damping-off and root rot mortality. A deliberate effort was made throughout the year to isolate Pythiaceous fungi from forest, nursery, and agricultural soils in order to accumulate specimens for taxonomic studies. Approximately 25 species of Pythium can be identified with certainty; 6 apparently new species have been encountered, and the existence of 2 distinct heterothallic species of Pythium has been verified. These heterothallic forms occur in Alberta, Canada; Washington, Oregon, Pennsylvania, and throughout the southern United States.

Preliminary results from a Polish study of the effect of pathogens on germination of pine and larch seed revealed that infected pine seed germinated better than the uninfected controls. In larch, germination was uniformly low and the presence or absence of pathogens had little if any effect. Similar studies are under way for oak and birch seed (PL-480).

Four hundred twenty isolates of a Gloeosporium spp., were obtained from seedling China fir in Taiwan and studied for morphological variation. Eight distinct cultural types were found to be present and these could be differentiated by their virulence to China fir as well as by growth characteristics (PL-480).

b. Nursery soils and chemical controls. Forest nurseries have for many years used soil fumigants for controlling soil-borne seedling diseases and weeds. The materials currently used require a plastic cover over treated nursery beds in order to be effective. A new material, with a mixture of dichloropropenes, dichloropropanes and methyl isothiocyanate as the active ingredients, was tested at Athens, Georgia. Without a cover it was not as effective as the standard treatment with methyl bromide but with a cover it was equal to methyl bromide. Nurserymen may prefer the new fumigant because it is easier and safer to handle than many other fumigants.

Aqueous extracts of pine duff were found to reduce populations of Fusarium oxysporum in forest soils of California. The extracts when applied to soil stimulated the resting structures to germinate and then killed the germlings. This effect of the extracts on F. oxysporum may explain the absence of Fusarium from forest soils.

Use of sawdust mulch in situations where oxygen is limited has resulted in tree root injury in the Pacific Northwest. Anaerobic microorganisms that develop on the woody materials promote fermentations that result in the formation of volatile organic acids. These acids and other end products from the fermentation processes can cause serious damage to the feeding roots of trees.

c. Susceptibility of American trees to foreign pathogens. Disease data were collected on 10 species of North American trees established in 50 experimental plantations in 16 forest districts in Poland. Replacement seedlings were planted where failures occurred due to abiotic factors such as frosts and drought. Four fungal pathogens were frequently recorded (Lophodermium pinastri, Armillaria mellea, Fomes annosus and Keithia thujina), but none were found in epidemic proportions (PL-480).

During the first year following activation of a Yugoslavia project to test susceptibility of North American conifers to foreign pathogens, seeds were planted in the nursery and measures devised to protect seedlings against birds and extreme solar heat. Estimates of seedling survival were made and requests sent to the United States for additional seed needed to fulfill planting requirements. Damping-off and Pestalotia needle blight caused moderate losses in the first-year seed beds (PL-480).

Periodic visits were made to the four project plantations in Sao Paulo, Brazil. No diseases of significance have been observed on any of the 12 provenances of introduced North American forest trees. Total losses occurred in Pinus strobus, P. ponderosa, and P. lambertiana at one location, apparently due to species inability to adapt to the site and/or environmental conditions (PL-480).

No serious disease problems were recorded in Colombia plantations of U.S. tree species. At Neusa the generally unfavorable climate prevented growth and in extreme cases killed the trees. A swelling of the root collar of a shortleaf pine in the Cali plantation has been associated with a Dasyscypha spp., not with the fusiform rust fungus as was originally suspected (PL-480).

Heavy, prolonged rains in the fall of 1966 in Uruguay caused chlorosis in Pinus taeda, P. radiata, and P. patula. Both Pinus elliotti and P. elliottii var. densa showed no chlorosis and actually produced good growth under the same conditions. Outbreaks of the needle blight caused by Diplodia pinea occurred in plantings of Pinus radiata. Buildup of the disease was associated with weakening due to other causes, e.g., poorly drained soils (PL-480).

2. Root diseases

a. Fomes annosus. Annosus root rot is threatening to become a major disease problem in the conifer forests of the West. In California, studies were conducted to determine the influence of pine root oleoresins on F. annosus. Contrary to past beliefs, resin production by pines being attacked by F. annosus is not an efficient defense mechanism. The fungus grows into heavily resined roots and can perpetuate itself for as long as 20 years, thereby creating a hazard to future forest plantations.

The temperature and relative humidity regimes in the stump habitat of Fomes annosus were studied in a pine plantation in Pennsylvania. The results indicate clearly that field experiments relating fungus activity to temperature or relative humidity must consider the micro-environment in the biosphere of the fungus rather than relating it to general above-ground measurements.

In a laboratory study of the influence of temperature on the growth and survival of F. annosus in wood it was found that the optimum growth rate occured at 24° C. and no growth occurred at 35° C. Actively growing mycelium in wood chips was killed in two hours at 40° C. Preliminary data revealed that stump surface temperatures near Durham, North Carolina, reached 40°C. or higher for two or more hours in over half of the days from May to August.

Based on the above laboratory studies it was decided to determine if seasonal thinning would be a practical means of reducing losses from annosus root rot. Plots were operationally thinned each month for 12 consecutive months in a slash pine plantation in southern Georgia. Both stump and air temperatures at stump height attained levels above the thermal inactivation time of mycelium for several consecutive days from April through September. Thinning operations conducted during this period should result in lower incidence of disease than those done during autumn and winter. A comparable study was conducted near Aulander, North Carolina, to determine if similar results would be obtained farther north. The data indicated a shorter safe thinning period for this area than exists in south Georgia but the safe period may be due more to the lack of inoculum than critical temperatures for stump infection.

Reforestation of areas clear-cut because of heavy infestation by F. annosus is a problem faced by many forest managers. There has been no information concerning what losses, if any, might be expected when replanting such areas in the Southeast. In replant studies established 4 years ago, initial losses ranged from 0.5 - 5.0 percent of the stand. Subsequent annual losses have been less than 1 percent. The fungus is still active in the stumps and mortality is expected to continue in the future.

Root bark has been considered a deterrent to replacement of F. annosus by antagonistic soil-borne organisms. However, in studies of the saprophytic activity of F. annosus and its survival in stumps, no replacement of F. annosus by other microorganisms occurred after 5 months when strips of bark 6 - 12 inches long were removed from the roots. This indicates that once F. annosus is established in the roots, it will not be readily replaced by other microorganisms.

In further studies on how direct root infection by F. annosus takes place, it was shown that an inoculum level of less than 1 conidium per ml. was sufficient to cause infection of the cut end of root pieces buried in the soil. Direct infection through the bark occurred at an inoculum level of 20 spores per ml. Inoculated root sections were readily colonized even when placed in the litter and A horizons where competition from other microorganisms is greatest.

Certain aspects of research with Fomes annosus have been hindered by lack of a reliable method for inoculating pine seedlings with the pathogen. Numerous techniques with seedlings growing in non-sterile soil have been tried over the last 3 years but infection and resultant mortality for the most part has been less than 10 percent, even when seedlings were in close contact with infected material bearing fruiting bodies of F. annosus. Using new techniques recently developed, inoculation of seedlings less than six weeks old under sterile conditions results in 100 percent

mortality under all experimental conditions tested: dark versus light, differences in substrate and substrate pH, and moisture, seedling age, host species, and isolate variation.

Evaluation after 4 years of large-scale stump treatment studies with ammonium fluoride and creosote showed a higher percentage of treated stumps to be infected with Fomes annosus than non-treated. A 3-month evaluation of these North Carolina studies had indicated almost complete control with both chemicals. Trichoderma spp., reported to be effective antagonists against F. annosus, were isolated from all fluoride-treated stumps.

In Poland, several hundred fungal isolates were made from pine litter, soil, rhizosphere, roots, and stumps in stands with and without F. annosus infections. For the 15 most frequent isolates in each group their influence on the growth of F. annosus in culture is being determined (PL-480).

b. Douglas-fir root rot (Poria weirii). Recently completed work in Oregon revealed that populations of soil fungi associated with Poria weirii include a great many species, but few are antagonistic to or parasitic on the pathogen in the laboratory. Total populations are highest in the dry months of summer, but the relative proportions of strong antagonists such as Trichoderma spp. remain fairly constant throughout the year. Mycorrhizal fungi are now known to protect tree rootlets from pathogens, but some mycorrhizal fungi are far more effective than others. Research with pure-culture techniques has demonstrated that Rhizopogon vinicolor , Lactarius sanquifluus, and Thelephora terrestris form mycorrhizae with Douglas-fir. Biochemical analyses of these and other mycorrhizal fungi have shown that species differ markedly in the biologically active compounds produced. Some of these compounds may be important in protecting roots from pathogens.

Many soil microbes that inhibit P. weirii thrive on nitrate whereas P. weirii cannot use nitrate nitrogen for lack of the enzyme nitrate reductase. Nitrogen-fixing alder root nodules result in high nitrate levels and increase the kinds and numbers of Poria-inhibiting organisms.

A possible biochemical explanation for the resistance of red alder to Poria weirii infection and the high susceptibility of Douglas-fir has been advanced by Pacific Northwest Station personnel. Alder tissue has a high activity of the enzyme polyphenol oxidase and a high content of phenolic compounds. P. weirii also secretes the enzyme, and this added amount of enzyme speeds oxidation of the phenols to form materials toxic to the fungus. Douglas-fir lacks both the polyphenol oxidase system and the phenols that are made fungi-toxic so infection can take place. These

findings may aid the search for Poria-resistant strains of Douglas-fir.

c. Other root pathogens. A Leptographium-type fungus was consistently isolated from the roots of eastern white pine in Ohio. Cankered stems and girdled root crowns have resulted in an unexplained mortality of trees in all crown classes and on various exposures and sites.

Cylindrocladium scoparium, the cause of a common root and collar rot of nursery seedlings and first-year outplant trees, was isolated from brownish-black necrotic areas in the cortical region of roots from dead and dying yellow poplar (Liriodendron tulipifera) in a 27-year-old plantation near Watkinsville, Georgia. This report is the first to associate this fungus with extensive root damage and mortality in trees beyond the seedling stage.

Polyporus tomentosus, the cause of red root and butt rot, was reported in slash pine (Pinus elliottii var. elliotti)plantations in South Carolina and Georgia. Sporophores of the fungus were always found fruiting on the face of basal stem cankers caused by Cronartium fusiforme. All collected sporophores were P. tomentosus var. circinatus. Of 446 basal C. fusiforme cankers examined in one Georgia plantation 8 percent were infected with P. tomentosus. This research confirms the association between this butt rot fungus and basal fusiform rust cankers and emphasizes an additional problem in southern pine management.

d. Soil microbiology. A huge landslide, falling from far above timberline on Mount Rainier in Washington in 1963, covered the floor of a montane valley with nearly virgin soil. This provided a unique opportunity to study succissional ecology of soil organisms in a forested zone. Sampling and analysis of soils over 2 ½ years reveals marked differences in microorganisms and in carbon and nitrogen content between the avalanche soil and nearby 70-year-old glacial moraine soils. Future studies should yield knowledge of how to manipulate soils and organisms for biological control of root diseases.

Forest Service grant-supported studies with the Brooklyn Botanic Garden in New York indicate that root exudates differentially stimulate or inhibit growth of gram-positive and gram-negative bacteria depending on the species and age of plants being tested. Gram staining characteristics of bacteria are closely linked with other characters such as their ability to withstand antibiotics. Investigations along this line are being continued, with emphasis on the root pathogens Fomes annosus, Armillaria mellea, and Rhizoctonia spp.

e. Mycorrhizae. Collarobarion between scientists of the Pacific Northwest Station and the Mexican Instituto Nacional de Investigaciones Forestales

has revealed that the antibiotic-producing mycorrhizal fungus, Cenococcum graniforme, occurs in Mexico as well as in the United States.

A basic study of rootlet anatomy and mycorrhizal fungi of sugar maple was completed during investigations of dieback in old-growth hardwood stands in northern Michigan. A description of developmental anatomy and the factors affecting the life cycle of a hardwood mycorrhizal fungus has been published.

Fungi associated with sweetgum mycorrhizae in Mississippi have been enumerated in recent results of pure culture studies. Of 21 fungi tested, 14 were found to be symbionts with sweetgum; 5 of these have not previously been recognized as mycorrhizal.

f. Nematodes. Of 7 species of Criconemoides found in New Mexico soils, 2 are new species. Thirty plant-parasitic nematode species representing 14 genera were found associated with marginal Pinus ponderosa and its woodland associates, P. edulis and Juniperus spp. The most widely distributed nematodes were Aphelenchoides spp., Xiphenema americanum, and Tylenchus exiguus; however, the most frequently encountered one was T. exiguus. The most abundant were species of Helicotyclenchus. Plant-parasitic nematodes were slightly more abundant in non-drought areas than in drought areas and were more abundant on Juniperus spp. than on Pinus spp.

An underscribed species of Aphelenchoides greatly reduced the diameter growth of aerial and substrate mycelium of a mycorrhizal and a pseudomycorrhizal fungus. The nematode reproduced readily on both fungi and destroyed 87 percent of the former but failed to completely destroy the latter. It was unable to maintain itself on an agar medium without the fungi.

In maple blight and maple dieback areas of Wisconsin forty-eight species representing 33 genera of plant-parasitic, saprophagous, other free-living, and predacious nematodes were found. Essentially the same nematode species were found in healthy maple stands and in maple blight and maple dieback areas, but they differed in relative abundance. Many plant-parasitic nematodes associated with the roots of maple also were found on roots of other tree species of the northern hardwood forest type.

A new species of root-knot nematode, Meloidogyne ovalis, was found parasitizing roots of sugar maple, American elm, and white ash in Massachusetts. Numerous galls were formed at the root tips. Proliferation of lateral rootlets occurred above the galls. In the greenhouse, this nematode reproduced on seven woody plant species but failed to reproduce on 29 herbaceous species.

3. Stem diseases.

a. Native rusts of conifers. Conversion of large areas in eastern Tennessee from scrub oak to loblolly pine over the past few years has created extensive acreages of a pine species highly susceptible to the introduced comandra rust. The incidence of rust infection within some plantations ranges from a trace to over 90 percent of the trees. Spread of the disease may be limited by the relative scarcity of the alternate host, Comandra umbellata, in most of the natural range of loblolly pine.

Abundant comandra blister rust damage in Utah lodgepole pine was first noted in the mid-1950's. It was suggested that overgrazing might have promoted the alternate host, comandra, to increase to a point that allowed large-scale outbreaks of the rust in pine. Recent analysis, in cooperation with range scientists, suggests that overgrazing did not bring about an increase in the abundance of comandra. In fact, heavy spring grazing by sheep markedly reduces the host plant.

Studies at Ogden, Utah, continue to add new information about the influence of environment on Cronartium comandrae. Aeciospores germinate well from about 5^{o} to 25^{o} C. with a peak near 13^{o} C.

Urediniospores germinate well from about 7^{o} to 26^{o} C. with an optimum nearer 18^{o} C. In greenhouse trials, infection of lodgepole pine with telial inoculum occurred at temperatures from 10^{o} to 20^{o} C. Field conditions in the Rocky Mountains are generally favorable for spread and intensification of Cronartium comandrae on comandra, but insufficient moisture and cool temperatures usually inhibit infection of pines.

While parasitizing their regular pine hosts, Cronartium comandrae and Peridermium filamentosum can also parasitize strands of dwarfmistletoe sinkers growing in the bark of western pines. This discovery suggests that the specificity of rust fungi to only certain hosts may not always be related to internal physiological interactions.

Recent work at the Intermountain Station has clarified the literature on hosts and distribution of the stem rust of hard pines caused by Cronartium comptoniae. The studies have improved evaluation techniques for distinguishing between C. comptoniae and Peridermium stalactiforme on pines.

Two methods have been developed at Berkeley for inoculation of ponderosa pines with western gall rust. One method successfully inoculated 92 percent of saplings enclosed in a plastic tent. A second method inoculated current-season growth on arboretum trees. Multiple kinds of resistance to

western gall rust in ponderosa pine are suggested by variations in type and rate of gall formation after experimental inoculation.

The rust Uredo phoradendri is a widespread but rather uncommon parasite of various mistletoes, Phoradendron spp. It was found recently on Phoradendron balleaum var. pauciflorum, a parasite of Abies concolor in Baja California. The report was the first on this host and the first from Mexico. Knowledge of the host range and distribution of the parasite is important in studies toward its use as a biological control agent.

b. White pine blister rust. Study of the comparative performance of clonal and seedling lines from selections of blister rust-free trees revealed that 4 percent of grafts from rust-free lines became infected whereas 89 percent of control seedlings became infected under the same external conditions. Most rust-free western selections in this Idaho study were genotypically as well as phenotypically resistant. Performance of selfed lines indicated that resistance probably is not controlled by single recessive genes.

Comparisons of foliage and bark sugars, amino acids, organic acids, phenolics, anthrocyanins, chlorophylls, carotene, macronutrient elements, dry matter content, monoterpenes and reactions to pectic and cellulolytic enzymes so far have failed to reveal clear differences between rust-resistant and rust-susceptible western white pines in Idaho.

Significant gains have been made in the technology of testing pines for blister rust resistance. Individual crosses made with equal-volume mixtures of 10 or more pollens of trees with high general combining ability are useful in defining the combining ability of new candidates being tested for transmission of rust resistance. As a result of this research three applied blister rust resistance breeding programs are underway in Forest Service Regions 1, 6 and 9.

The results have been analyzed from 3 Moscow experiments in which 128 new, canker-free, candidate "resistant" pines were mated to each of 4 tester trees and the progenies then artificially inoculated at age one. The general combining ability averaged 2 to 4 times as great as specific combining ability. This means that selection of healthy trees in heavily infected wild stands or nursery seedbeds is a highly productive process which will lead to relatively rapid gain in resistance per generation of breeding.

From Oregon studies of the growth rate and survival of blister rust cankers it is now known that cankers grow significantly slower on young sugar pine branches in southern Oregon than on young western white pine in Northern Idaho. The probability that a branch canker will reach the

trunk is lower than for a comparable canker on western white pine. Removal of branch cankers may not be necessary to protect the bole in some sugar pine and costly pruning may be eliminated. Research has provided a means of estimating the time required for the sugar pine branch canker to reach the bole and the probability that it will do so before harvest age.

Basal-stem applications of cyclohexamide and Phytoactin on white pine blister rust on sugar pine in Oregon and California failed to control cankers above the application zone. Bioassays indicate the cyclohexamide is translocated in sugar pine at such low levels that it may be confused with naturally occurring antifungal materials present in needle tissue.

Partially purified Phytoactin and its purified components, A and B, were labelled with radioactive tritium in order to trace their movement in white pine seedlings. Five days after application, on current and mature needles and at the stem base, increased radioactivity was noted in different portions of the upper crown. The pattern of distribution indicates selective accumulation of radioactivity on mature needles and suggests that Phytoactin can act in a systemic manner. Phytoactins A and B can be extracted as separate fractions from treated western white pine tissues and assayed (against the test fungus Glomerella cingulata). Concentrations of Phytoactin B as low as $\frac{1}{2}$ppm in tissue can be assayed; Phytoactin A is difficult to detect below 250 ppm. These findings resulted from cooperative studies between Washington State University and the Intermountain Station.

Progress was made in 1966 toward an understanding of how to differentiate between living and dead tissues of the blister rust fungus and those of the pine tree. Biochemical investigations aimed at localization of specific dehydrogenases in diseased pine tissues were completed at Moscow. The use of tetrazolium salts to determine the distribution of individual dehydrogenases has been hampered in plant tissue research apparently because of inactivation of these enzymes in frozen plant tissues. A freezing procedure was developed to obtain reaction-free material and to localize a number of dehydrogenases. Subsequent studies have helped determine the precision of this localization and the factors that affect this precision.

The NB tetrazolium technique has utility for identification of live versus dead Cronartium ribicola tissue in cankers but is not a useful tool for forecasting the potential of the rust fungus in terms of growth. When an enzyme vital to metabolism is shown to be absent with the tetrazolium test, one can conclude that life is nonexistent and growth is not possible. The fact that certain enzymes are present and can be identified indicates that the organism is potentially capable of metabolism but does not answer the question of whether the net effect of metabolism will be growth or death of the organism.

Both a method and a medium for obtaining and maintaining tissue cultures of Pinus monticola have been developed at Moscow. Cambial explants can be cultured on a chemically defined medium containing six nutrient salts, glucose, and one of three auxins, i e., IAA, NAA, or 2,4-D. Addition of several B vitamins, amino acids, and kinetin have increased growth on the media developed but are not required. Callus has been subcultured from cambial explants every month for the past 14 months with little or no volume growth reduction in successive transplants.

The conditions necessary for eastern white pine needle infection by Cronartium ribicola have been delineated as a result of research sponsored by a Forest Service grant to the University of Wisconsin. With this knowledge, critical study of resistance and resistance mechanisms can now be made. Needle infection through stomata has been demonstrated consistently and conclusively. Not a single instance of direct surface penetration was observed. The critical factor necessary for controlling needle infection has been found to be diurnal temperature fluctuation within a range of 40-75 degrees F. These fluctuations induce germ tubes to penetrate between guard cells and form vesicles which give rise to infection hyphae.

Electron microscope studies at Berkeley, California, have shown how the white pine blister rust fungus forms its pine-infecting spores. Dissemination appears to be based on the forceful discharge mechanism of the spore which violently propels it away from the leaf surface out into surrounding air currents.

The purple mold fungus, Tuberculina maxima, a hyperparasite on the white pine blister rust fungus, has been found to be common on rust-infected sugar pines on Hatchet Mountain, Shasta County, California. It suppresses but apparently seldom controls affected rust cankers on sugar pine. Prevalence of the purple mold on test areas has increased the difficulty in assessing results of fungicidal treatments of rust cankers.

c. Fusiform rust. The key to amount of damage to pines by fusiform rust is the amount of fungus inoculum on the oak alternate hosts and the capacity of this inoculum to produce sporidia which infect the pines. The time during which these sporidia are produced also delineates the period of maximum infection hazard to the pines. Maximum germinative capacity of the oak inoculum occurred in South Carolina within a 3-week period from late April through mid-May. The production of inoculum declined each succeeding week after that time, and by June had essentially stopped. This indicated that the pines are relatively safe from disease attack after a brief period in the spring. If future economic factors permit the use of sprays for rust control, the application of these control measures could safely be limited to this period of high-infection hazard.

One of the primary obstacles in the study of fusiform rust has been the brief annual occurrence of the aecial, uredial, and telial stage of the fungus which limited the time during which research could be carried out. To provide material for research throughout the year, an efficient preservation method was needed. Research at Macon, Georgia developed a vacuum-drying technique which has maintained the viability of stored aeciospores over a year and may well exceed this period of time. Procedures for gradual spore rehydration prior to use after storage were also developed.

At Gulfport, Mississippi, detailed observations for two successive years revealed that maximum aecial sporulation occurs when oak-leaf emergence is most rapid. Any factors which could delay emergence of oak leaves will reduce the incidence of fusiform rust.

The submicroscopic structure of aeciospores before and during germination was studied and comparisons were made between the white and orange strains of Cronartium fusiforme under the research grant program at the University of Mississippi Medical Center. No physical differences were observed between the white and orange strains at the microscopic or submicroscopic level. On the basis of nutritional studies with carbon-14 as a tracer, evidence was presented that the fungus actively uses oleic acid as a primary substrate for germinating and actively respiring aeciospores. This usage appears to be inhibited by the presence of fatty acids. Pine callus and individual pine cells were maintained in tissue culture for periods up to a year.

d. Canker diseases. A complex of fungi is associated with Ceratocystis cankers of aspen in the northern Rocky Mountains. Three species of Ceratocystis, in additon to C. fimbriata which had been reported to be the causal agent, have been found on the cankers. Since Ceratocystis seems to be the only genus involved, insect vectors probably explain the spotty distribution of the cankers. Ceratocystis canker, previously known only in the central Rocky Mountains and the Lake States, is now known to occur in Idaho, Nevada, and northern California.

Northeastern Station results of initial trials using infrared aerial photography to map distribution patterns and appraise changes in disease condition of pines affected by basal canker showed sufficient promise to warrant further experimentation. In many instances foliage of cankered trees not yet visibly altered was distinguishable on infrared film.

A bark pathogen, Cephalosporium spp., was isolated from the margins of cankers and from diseased sapwood of European black alders planted on

strip-mine banks in Kentucky. Localized lesions were produced when this fungus was reinoculated into older trees. Apparently, the debilitating effects of insects and sooty mold infestations, coupled with environmental stresses, predisposed the spoils-bank trees to invasion by this weak pathogen.

Further analyses of data from a survey of Scleroderris lagerbergii canker in red and jack pine plantations in upper Michigan and Wisconsin reaffirm earlier predictions of the seriousness of the disease. The causal fungus was found in 66 percent of the red pine plantations and 86 percent of the jack pine plantations sampled. Mortality in these red and jack pine plantations averaged 40 and 39 percent respectively.

Scleroderris canker surveys conducted during the past year revealed that this disease is also present in a few counties in the northern part of the Lower Peninsula of Michigan and that it is widespread and severe on State-owned lands in the Upper Peninsula of Michigan. It was not found in Minnesota. Studies of the causual fungus have shown that the airborne ascospores are disseminated from May to October, with a higher level in July and August. Most of the spores are disseminated within 48 hours after a rain. Free moisture is required for release of ascospores and for germination of both ascospores and conidia. Ascospores are released over the temperature range from 0 to 29° C., with the maximum release at about 17°C.

During the spring of 1966, unprecedented severe damage to red pine nursery stock occurred in nurseries throughout the northern part of the Lake States, with resultant substantial destruction of nursery stock and curtailment planting programs. New plantations also suffered heavy losses. In some areas, first-season mortality averaged 95 percent. At first this situation was believed to be caused by Scleroderris canker but to date, intensive efforts to isolate the causal organism have been negative for Scleroderris. The cause remains unknown.

Research is continuing at St. Paul on the basic biology of the hypoxylon canker fungus. In an attempt to learn how the fungus becomes established in a host tree, a nursery seedbed of aspen was inoculated with ascospores in a manner similar to that used to successfully inoculate seedlings with various tree rust fungi. Fifteen months after treatment there was no evidence of infection. A representative sample of these seedlings has been planted in greenhouse pots where they will be observed for some time to determine whether symptoms might yet develop.

Cultural and physiological studies are underway on Nectria pterospermum, a canker-producing fungus with a rather wide host range in Taiwan.

Indol-3-acetic acid (IAA) was found to be higher in diseased tissues than in healthy tissues. It is believed the Nectria produces the excess IAA which in turn causes excessive growth of the cambium and the resultant cracking of the bark to initiate the canker (PL-480).

e. Dwarfmistletoes. Dwarfmistletoe reduces height growth even more than diameter growth. Determination of total infection impact will be about 40 percent too low if effect on height growth is ignored, and about 10 percent too low if impact on height growth is assumed to be the same as on diameter growth. Previous estimates of the impact of dwarfmistletoes in the Pacific Northeast probably were low. More reliable damage estimates for ponderosa pine should now be possible.

Two herbicides show some promise for development of satisfactory control of dwarfmistletoes on pine in California. The material 2,4,5-trichlorophenoxy butyric acid appears promising as a direct control, and 2,4,5-trichlorophenoxy propionic acid as a systemic control.

The dwarfmistletoes (Arceuthobium spp.) are highly developed parasitic plants which have undergone extreme morphological reduction. As a result, these plants are not amenable to conventional taxonomic classification techniques which rely heavily on morphology. Thus pollen, host relations, phenology, geographic distribution, cytology, and chromatography of shoot pigments have been studied in attempts to determine taxonomic relationships. At Fort Collins, Colorado, preliminary analyses suggest that it will be possible to develop a computerized classification of Arceuthobium. Machine runs have already revealed that some dwarfmistletoes which were thought to be related at the sub-specific level should be considered as distinct species.

Some new dwarfmistletoe records by Rocky Mountain Station personnel include: (1) The discovery of pinyon dwarfmistletoe, A. campylopodum f. divaricatum, for the first time on Mexican pinyon, Pinus cembroides (Davis Mountains of western Texas); (2) the first report of the white fir dwarfmistletoe, A. campylopodum f. abietinum, from Utah; and (3) the first sugar pine dwarfmistletoe, A. campylopodum f. blumeri, from Oregon. Greenhouse inoculations showed that eastern white pine, Pinus strobus, is very susceptible to the limber pine dwarfmistletoe, A. campylopodum f. cyanocarpum.

Collection of Arceuthobium seeds for research purposes at the Intermountain Station was best accomplished by "trapping" naturally expelled seeds in paper, cheesecloth, or sausage-casing bags. Seeds stored in the laboratory under dry, cold (5°C.) conditions or in the field during the winter in cheesecloth or sausage-casing bags retained their viability for 6

months or more. Stratification, moist cold storage, and storage at room temperature (23°C.) proved unsatisfactory for seeds of six taxa. Molds destroy the seeds when moisture is excessive, both in the laboratory and field. The techniques recommended here should insure efficient collection and safe storage of valuable study material.

Studies of dwarfmistletoe on red fir in California continue to turn up new and important information. Number of trees infected and number of infections per infected tree are more closely related to tree height than to tree age. Although number of infections per infected tree increases with tree height the number of infections per square foot of surface area of tree crown remains more or less constant. Needle bearing branches of all ages are susceptible to infection but branches less than 10 years old are most vulnerable. Bole infections accounted for less than 10 percent of all the fir infections tallied. Branch and bole infections in the study ranged from 1 to 30 years in age with an average age of about 5 years for branch infection and 10 years for bole infection. Trees up to 3 feet in height were found to be relatively free of dwarfmistletoe even in the presence of heavy overstory infection. This means that fir stands may be regenerated and allowed to grow for several years in the presence of infected overstory without appreciable attack and buildup of dwarfmistletoe.

On the multiple-aged stands of ponderosa pine at Grand Canyon National Park, dwarfmistletoe-caused mortality and growth reduction offset increment in both moderate and heavy infection classes over a 10-year period. During essentially the same period in the pole-size stands of the Mescalero-Apache Indian Reservation, however, net loss in basal area occurred only in the heaviest infection class.

Development of latent and missed infections in New Mixico necessitated recleaning an area of 9,059 acres 8 to 9 years after the original cleaning. The recleaning reduced the dwarfmistletoe infection to less than 1 percent--the same level achieved originally. Cost of the recleaning was $7.09 per acre compared to $5.26 for the original operation. Increased costs were mainly due to three factors: (1) As fewer infected trees were found during recleaning, more time was spent per tree in searching for infections. (2) The trees treated during recleaning were generally larger than those treated earlier, and sawyer's time is more expensive than that of axmen. (3) The cost of labor increased substantially between operations.

f. Mistletoes. The mistletoes of the genus Phoradendron occasionally damage coniferous forests and are widespread in hardwoods. Cooperative studies between Rocky Mountain Experiment Station and Colorado State University researchers are designed to determine their importance in the west. A number of previously unreported phenomena in Phoradendron have been observed. Witches' brooms caused by Phoradendron are reported for the first time; P. tomentosum in Foquieria in Mexico and P. juniperinum on junipers in Utah. Autoparasitism (a mistletoe growing on anotner individual of the same species is reported in three species--P. californicum, P. villosum, and P. tomentosum. Phoradendron villosum subsp. coryae was found as a hyper-parasite of P. juniperinum.

In studies of the carbohydrate metabolism of the mistletoe Dendrophthoe falcata in India it was shown that significant quantitative and qualitative differences existed between the parasite leaves and the host leaves as to carbohydrate composition. Mistletoe leaves contained a higher concentration of acid-soluble phosphate than measured in leaves of host species of Cassia, Mangifera, and Psidium. The acid-labile phosphate constituted a much lower and the acid-stable phosphate a higher percentage in the parasite than in the host leaf in all three host species. During investigation of the activity of phosphorylase as a key enzyme in carbohydrate metabolism a powerful innibitor of the enzyme was discovered. Attempts are underway to eliminate the infulence of the inhibitor. Use of selected agents such as polyvinyl pyrrolidone, tween and charcoal have led to only partial success in such elimination (PL-480).

g. Heartrots. Analysis of data from an aspen dissection study involving 850 trees from 48 different sites in Wisconsin and the Upper Peninsula of Michigan is being completed. The field data were gathered by the Kimberly Clark Corporation. It has been found that almost all of the sample trees had some type of defect, with less than 1 percent being classed as completely sound. Total defect was equal to approximately 20 percent of the gross volume of these trees. Stain was the most common type of defect encountered, with over 90 percent of the sample trees affected. Decay was present in fewer than half of the trees.

Twenty-two species of fungi were found in association with decay in living oaks in Kentucky. Four species, Polyporus compactus, Stereum frustulatum, S. gausapatum, and Poria cocos accounted for almost 60 percent of the 302 identified infections. Poria cocos and P. nigra accounted for over one-third of the total decay volume. One-fourth of all infections took place through fire scars and over one-third of the total decay volume was associated with fire scars.

Red rot, caused by Polyporus anceps, is the major defect of merchantable ponderosa pine in the Black Hills National Forest. Total defect in 500 study trees amounted to 19.2 percent of the gross board-foot volume, of which 15.9 percent was due to decay. Red rot accounted for 8.6 percent and brown cubical rots 7.3 percent of the gross volume. The remaining 3.3 percent was attributed to cat faces, checks, forks, crooks, sweep, scars, and other defects. Red rot was present in 68 percent of the trees. Brown rot was present in only 36 percent of the trees, but the total defect it caused was nearly as great as that caused by red rot. Red rot volume increased with age in the Black Hills pine. It probably will be the only rot of consequence in second-growth timber.

Early results of a Northeastern Station investigation of the tissue changes that occur after wounding suggest that anatomical changes may account in large part for the restrictions of discolorations and decays to tissue present when the trees were wounded. The most significant changes occurred in the ray cells. In discolored tissues, altered cells contained many different types of materials indicating that discolorations probably resulted from many different processes. Related studies of the bacteria associated with discolorations were continued and representative isolates were assayed for thiamine production. All bacteria isolated to date from northern hardwoods produced this vitamin essential for growth of many decay fungi.

Decay cull volumes are difficult to estimate in standing Engelmann spruce in Colorado. The resulting errors in cruising timber lead to hardship and dissatisfaction on the part of timber purchasers. It has been found that 11 types of abnormalities are good indicators of decay in merchantable Engelmann spruce. Fomes pini is the most important decay fungus, and it can usually be detected by external indicators. As cull from decay on the sample plots was estimated within 1 percent of the scaled volume, use of the indicators should improve timber sale appraisals and log scaling in Engelmann spruce.

Many upper-slope coniferous forests in eastern Oregon and Washington are highly defective. Increased forest management and demands for raw material and recreational areas has focused attention on these forests. Defect percentages, in terms of cubic- and board-foot volumes, have been tabulated by diameter, age, and indicator classes for grand fir and Engelmann spruce; by diameter, age, and indicator classes for grand fir and by indicator classes for western larch. A publication based on these data provides the first reliable methods for estimating defect in these increasingly important forests.

On California recreation sites administered by Federal agencies, more than two injuries or deaths per year have been caused over the past 8 years by tree hazards. Property damage, exclusive of clean-up costs, exceeds $25,000 per year on the limited acreages surveyed. Pines and firs have caused the majority of the troubles. Forty percent of reported failures have caused human injuries or serious damage to property. For all species on all sites, uprooting is by far the most common type of failure, followed by bole, branch, and butt failure through decay. Knowledge of the most susceptible species and the types and causes of failures will permit more efficient hazard control efforts aimed at the primary sources of danger.

Potentially hazardous lodgepole pine were found to be common on selected California recreational sites. One-third of all trees examined had butt rot; one half of these decayed trees were rated potentially hazardous because of the butt rot. All decayed trees of 35-inch d.b.h. or more (200 + years) were potentially hazardous. Of trees with fire scars, two-thirds were decayed and one-half of these were hazardous. Hazard inspections of lodgepole pine should be more comprehensive in recreational areas where much of the timber is not only overmature but exempt from commercial cutting.

4. Foliage Diseases

a. Needle casts. Studies on Elytroderma needle cast of ponderosa pine in the Pacific Northwest have provided guidelines for the management of infected trees and forest stands. Results from the study are numerous. The fungus is perennial within the host where it spreads vegetatively from one twig or branch to another. Growth rates are reduced proportionately to the crown damage. Young uncrowded ponderosa pines with healthy leaders usually recover if not attacked by other parasites. In mature stands, crown damage from extensive killing of twigs and branches is permament; moderately infected trees are more susceptible to root disease and beetle attack; heavily infected trees are often killed directly by defoliation.

Cooperative investigations at the University of Montana have revealed several previously unknown cytol gical features in the fungus family Hypodermataceae, causing needle cast of western conifers. From studies of the morphology of the fruiting bodies of 39 species in this family, two basic and one intermediate type of formations have been described. Spore initiation differs between types I and II, whereas in the intermediate type the developmental sequences are similar to those in both I and II.

In a related investigation, the development of the ascocarp of Hypodermella arcuata has been described as type I. Life cycle studies of the disease on western white pine indicate that ascospores germinate from either end by short germ tubes, form appressoria, and probably penetrate the needle through the cuticle and epidermis.

The fungus Hypoderma mexicanum frequently causes serious damage in Mexico, particularly in young pine stands in western Chihuahua and Durango. It was recently collected and identified in collaboration between the Rocky Mountain Station and the Instituto Nacional de Investigaciones Forestales of Mexico City. New hosts for the fungus include Pinus cooperi, P. durangensis, and P. engelmannii.

b. Needle blights. Conidia of Dothistroma pini were trapped in late spring and throughout the summer in Nebraska, but only during periods when rain fell. The conidia germinated over a temperature range of 12-28°C.; germ tubes were longest at 24°C. Germ tubes penetrated needles of both Pinus nigra and P. ponderosa through stomata. Initial infection occurred June 16-23 in 1964; May 20-27 in 1965. Disease symptoms were not evident until 4 months after initial infection.

D. pini has been definitely identified as the cause of the needle disease of Pinus radiata in Chile. Seventeen percent of the trees in one plantation have been killed. Control measures developed in North America and Africa are now being put into practice. Under Chilean conditions, the disease also attacks Douglas-fir, the only place it has been found on this host.

Blight caused by Cercospora sequoiae is a serious threat to established plantings (shelterbelts) of eastern redcedar (Juniperus virginiana) and Rocky Mountain juniper in eastern and central Nebraska. Good control of this fungus was obtained with three to five applications of Bordeaux mixture (8-8-100) applied at 3-week intervals beginning in early May.

c. Air pollution. Tests were established in Alabama and Tennessee to determine the suitability of eastern white pine as biological indicators of air pollution. In Alabama 570 seedlings were exposed to an atmosphere containing high concentrations of fluorides. After 1 year 63 seedling pines were dead, 109 severly injured, 277 slightly injured, and 121 grew vigorously. The survivors will be reexposed in other areas where different types of pollution occur. Seedlings susceptible to one of several specific pollutants and resistant to all others will be maintained to be used as part of a proposed pollution monitoring system.

In continuation of work previously reported, 26 eastern white pine seedlings were exposed in an urban atmosphere in Tennessee where high concentrations of oxidants are known to occur. All of these seedlings were known to be resistant to both sulfur dioxide and fluorides. Five of these trees died and 12 were susceptible to the oxidants. The 9 trees resistant to oxidants will be further tested as "superseedlings" resistant to all three toxicants.

d. Pine twist rust. In Italy it has been postulated that two races of Melampsora pinitorqua exist: one specialized on Pinus and the other on Larix. Experiments have been designed to test this theory. Studies of the germination of the rust-infecting spores indicate that optimum temperature is between 13°C. and 15°C. for uredospores, and that a time interval of 24 hours is necessary for maximum germination at all temperatures tested. Aeciospore infections can occur from 0°C. to 22°C. Meteorological data are being collected to determine the conditions that lead to epidemics in natural and artificial stands. Chemical control tests revealed that non-cupric fungicides effectively controlled the rust while copper fungicides gave no control (PL-480).

e. Miscellaneous. Investigations of causes and effects of widespread dieback of northern hardwoods in the Lake States indicate that fears of a general decline are unwarranted. The single readily-apparent symptom, death of a portion of the crown, has two major causes; abnormally high water tables in early spring, and sudden exposure resulting from heavy cuttings. There is evidence of several cycles of dieback and recovery during the past 30 years which correlate well with periods of high precipitation in the spring. Many stands are now in a recovery phase.

The first year's results of a 3-year Northeastern Station study to determine the effects of defoliation upon food reserves in sugar maple has shown that defoliation not only markedly lowered food reserves, but that it also affected the kinds of sugars present in the roots and root collar tissues.

A disease of unknown cause is killing needles of ponderosa pine at several locations in Denver, Colorado, and in the foothills west of the city. Arboriculturists unsuccessfully applied soil amendments and pesticides. Laboratory examinations of roots and shoots proved negative for pathogens. Symptoms typical of air pollution injury are exhibited by severely affected trees.

5. Systemic diseases

a. Oak wilt. At Delaware, Ohio, fumigation with methyl bromide at concentrations of 5 pounds per 1,000 cubic feet of fumigation chamber space for 7 days at 75°F. or for 1 day at 100°F. has killed all the fungus in infected logs in repeated tests. Treatment at lower concentrations, lower temperatures, and of shorter duration have failed.

Results of initial trials in which logs are heated by hot air or hot water dip suggest that heat alone, well below levels that would cause log degrade, may be as effective as a fumigant. All of the fungus in infected logs has been killed by 24-hour exposure to 130°F. in air or 110°F. in water, and by 48-hour exposure to 110°F. in air or 100°F. in water. Further experimentation is underway.

In studies designed to provide a clearer understanding of the effect of the oak wilt disease on the physiology and biochemistry of the host plant, diseased and healthy Quercus macrocarpa split embryo paired seedlings were maintained under low relative humidity and controlled temperature and light conditions. It was found that as the disease progresses transpiration decreases rapidly over a short period of time. Invertase activity was greater in diseased than in healthy oak seedlings.

b. Miscellaneous. Western X-disease virus causes widespread mortality of common chokecherry (Prunus virginiana) in the Great Plains. Seed for nursery production is often obtained from shelterbelts; many chokecherry trees in shelterbelts are infected with this virus. However, no evidence was obtained that the virus is seed-transmitted so nurserymen may now use local seed with confidence.

6. Decay of wood and wood products

a. Decay of killed timber. Beetle-killed Douglas-fir occurs in scattered and often isolated pockets in the Pacific Northwest. Immediate salvage frequently is impossible and deterioration reduces sound volumes rapidly. Limitations on economic slavage involve complex interrelationships of tree age and size, time since death, and climatic factors. Descriptive and photographic guides were developed to enable forest managers to estimate the time of death; curves were provided to predict deterioration and felling breakage losses over time since death; and priorities for scheduling salvage operations were recommended. These guidelines will now enable forest managers to schedule salvage of beetle-killed Douglas-fir so as to recover volumes previously lost.

b. Decay and raw products. In the South, longleaf pine bolts stored under water spray were quickly invaded by bacteria and actinomycetes. This resulted in greater permeability of wood to preservatives and

a significant increase in decay resistance; stains did not penetrate more than one inch on end sections.

A cooperative study by the North Central Station and a Lake States paper mill provided indications that constant sprinkling of storage piles during the growing season may extend the risk-free period for winter-cut wood at least through the following November and probably longer. The results from this study, while not conclusive, are extremely promising and a more definitive test is underway. Sprinkling has the added advantage of easier debarking.

Bacteria are beginning to be recognized as large-scale invaders of water-soaked wood and, in many situations, are capable of damage. Pronounced bacterial infection developed in southern pine veneer logs stored under warm water. Work by Forest Products Laboratory researchers revealed that bacteria open up rays and resin ducts thus making the wood abnormally permeable. This affected veneer-cutting characteristics somewhat but had little adverse effect on mechanical properties.

In studies of deterioration rates of willow and cottonwood during storage in Georgia the maximum specific gravity loss in willow bolts was about 5 percent and in cottonwood 8 percent. Over one year's storage there was little change in fiber classification of the pulps. Data on the prevention of storage losses in logs and bolts assumes greater significance as the uses and demands for wood fiber products increase.

Characterizations of growth rates, temperature relations, oxidase production and relative wood-destroying capacity of the principal soft-rot fungi of pulp chips stored in the South have been completed. Many organisms attacking chips in large storage piles clearly differ from those mainly responsible for damage to pulpwood in the round. Familiarity with these new destructive agents is essential for development of appropriate methods to combat them.

The problem of stored pulp chips was also investigated in the Northeast. The identity of principal microorganisms, their relation to position of chips in the pile and to types of visible changes or damage in the wood, and their capacity to reduce specific gravity were ascertained. The isolates were grouped as mesophylic, thermotolerant and thermophylic based on their growth at 20° and 40°C. The behavior of such organisms in an atmosphere of high carbon dioxide content such as occurs in chip pile interiors is being investigated.

c. Decay of wood in use. A Forest Products Laboratory study of the decay of wood in Navy facilities revealed that decay was prevalent in all above-water components of piers and wharves. An economic analysis indicated clearly that preservative treatment of the structures and certain simple

maintenance practices are justifiable even in the drier U.S. climates.

The effect of soft-rot infection on exterior finish has been investigated. Infection of the wood surface prior to application of an oil-type finish did not cause the finish to loosen from the wood during exterior exposure in Wisconsin, nor in a constant high relative humidity in the laboratory. The degraded condition of the infected surfaces at the time of finishing, however, raises a question of whether the shallower penetrating emulsion type of paint would have adhered successfully.

In cooperation with engineers, forest products pathologists at Madison have conducted a study on timber bridges during the past 2 years. A serious decay situation and need for protective measures were found in Alaskan native-timber bridges. Experiments to evaluate deck seals and sealants to protect joints, bolt holes, and checks and splits have been initiated.

Forty-two species of fungi have been associated with decay of domestic utility poles. The fungi have been grouped by geographic regions and tree species. Decay potentials of the nine principal fungi were determined, as were the rates at which they may enlarge initial zones of decay and their capacities to enter the outer treated zone of wood.

d. Natural durability in wood. Many woods are naturally more resistant to decay than the best preservative-treated wood of nondurable species. Experimentation and a search of the literature disclosed 54 tree species in which fungus-inhibiting extractives of phenolic nature could account at least in part for natural decay resistance of the heartwood. Lesser resistance of inner heartwood is believed to be largely attributable to oxidative changes of the extractives to less potent compounds. The naturally occurring extractives offer valuable clues to means of substantially improving preservative treatments.

A cooperative study at St. Paul, Minnesota, attempted to explain some of the marked variation in wood decay susceptibility in above-ground situations. Germination of spores of decay fungi on wood was significantly inhibited by steaming the wood, by extracting water soluble substances from it, or by washing the spores in water. The inhibitory strength of pentachlorophenol solution on spore germination was only one-tenth as effective on treated wood as on nutrient agar. By seeking out the weaknesses in the capacity of fungal spores to germinate, improved wood-protection measures may be realized.

Specialized staining techniques in combination with fluorescent lighting disclose two radically new and significant facts about the nature of decay in wood. Enzymatic breakdown of the wood substance occurs in the

immediate vicinity of the fungus hyphae and is not widely diffused as once supposed. The enzymes are brought into the cell wall by very small microscopic hyphae such as previously have been known only for soft-rot fungi. Both facts help elucidate the progression of fungal attack on the microstructure of wood and the nature of decay resistance.

At Delaware, Ohio, investigations of the influence of environment on the ability of decay fungi to break down wood reveal that production of cellulase by these organisms can be varied by changing the temperature and the composition of gases in the environment. The cellulase system of one common organism, Stereum gausapatum is being characterized in detail in an attempt to throw light on wood durability or susceptibility to decay.

The role of nitrogen in wood deterioration has been investigated under a grant to North Carolina State University. The hypothesis is presented that trees possess an internal recycling mechanism for conservation and reuse of nitrogen in the cytoplasm of xylary cells. It is believed that nitrogen in the dying parenchyma cells in the heartwood is retrieved for reuse elsewhere in the tree. Hydrolysates of wood contain many protein amino acids which probably contribute to susceptibility to stain and decay fungi. Nitrogen extractions suggest that enzymes are needed to modify cellulose before the nitrogen in cell walls is available to fungi. It appears too that nitrogen required for sporulation of wood-destroying fungi is derived either from very large volumes of wood or from sources outside the wood itself.

Through accelerated laboratory investigations on decay of timbers, four decay resistance classes have been established in India. One hundred twelve samples from 27 wood species were tested during the reporting period for a total of 388 samples from 50 species since the project began Of these 50 species, 4 are represented by tests of 20 or more samples. Decay ratings are not considered valid unless at least 20 samples are tested. For conifers the test fungi are Poria monticola and Lenzites striata; for hardwoods, they are Polyporus sanguineus, P. versicolor, P. hirsutus, and P. palustris. The four reliably rated timbers are: Shorea robusta, Xylia xylocarpara, and Tectona grandis, all classified as very resistant; and Terminalia tomentosa as resistant (PL-480).

e. Causal fungi and their identification. The significance of the Fungi Imperfecti and Ascomycetes that inhabit wood was recognized with the discovery by Forest Products Laboratory personnel that some fungi of these groups are capable of causing a decay called soft rot. The soft-rot fungi are prevalent in situations of extreme wetness. With recent improvements in studying these fungi it is now evident that a large percentage of soft-rot isolates are able to digest the secondary walls of wood tracheids and fibers.

A detailed study of the little known fungus, Veluticeps berkeleyi, which causes decay in living ponderosa pine and other conifers in North America, has been made at the Beltsville Forest Disease Laboratory. Cultures, basidiocarps and the nature of the decay have been described.

The correct identity of the brown rot fungus, Polyporus meliae, has been ascertained by interfertility studies and the cultural characters have been described. The fungus is widely distributed in temperate, subtropical, and tropical regions and causes brown rot of both hardwood and conifer hosts. It has also been isolated from dead limbs of living peach trees and from wood in use.

During the year 48 wood decay species new to the Beltsville reference culture collection were acquired and 263 new haploid isolates made. The total collection has doubled in 9 years time and now numbers 12,309, including 2,570 haploid isolates, representing 207 species.

7. Miscellaneous disease studies

To determine what types of inoculum will cause infection in wood and under what environmental conditions infection is most likely to occur, studies at the Forest Products Laboratory were completed on the fungus Polyporus dryophilus. Spore germination could be promoted by increasing the carbon dioxide in the air. Alcohols, carbonates, and ethylene did not stimulate germination. Germinating spores tended to penetrate many others that had not germinated. Both germination and vegetative growth were enhanced by confinement of P. dryophilus with certain non-decaying fungi.

A portable gas analyzer was constructed and operated at Delaware, Ohio. The instrument is used to detect and measure oxygen and carbon dioxide in studies of decay progression in living trees. It is light enough and rugged enough for field use, requires only a small sample for analysis, and can be used to determine gas concentrations to the nearest 0.2 percent.

In cooperative work at Pennsylvania State University a spore trap for studying spore liberation from sporophores of bracket fungi was developed and tested. The trap and associated timing devices provides a means of sampling several sporophores simultaneously.

Peroxide and water treatments have been found to differentially affect the germination of and the microflora on seeds of six woody plants species in New Mexico. Besides improving germination, the peroxide treatment was very effective for reducing seed-borne microflora. By proper use of these techniques more seedlings can be obtained from a given quantity of seed.

Pedicularis centrantheca was found parasitizing roots of Juniperus monosperma, J. deppeana, and Pinus ponderosa. The parasite formed haustoria on the small rootlets of the host and produced a direct connection between its xylem vessels and the xylem tracheids of the host. The parasite is a perennial plant that is widely distributed in ponderosa pine forests and juniper woodlands in Arizona, Colorado, New Mexico, and Utah.

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IV. FOREST PRODUCTS AND ENGINEERING RESEARCH

A. FOREST PRODUCTS UTILIZATION RESEARCH

Problem

The forest products industry is an important segment of our total economy. About 6 percent of the gross national product originates in the timber-based industries. Shipments from timber-based primary manufacturing plants are valued at over $10 billion annually. One out of every 20 people employed in the U.S. works in these industries. The industry will become increasingly important as research alleviates problems in timber processing and opens up the opportunity to develop the industry's full potential. Major problems currently facing this industry include the continuing decline in quality of available timber because of the lack of adequate replacements for the larger and better quality trees that make up the bulk of timber harvest and the 32 percent of timber volume, 12 percent as logging residues and 20 percent as plant residue or fuel, which now makes no contribution to supply.

The increasing demand for timber products, which is expected to go up 80 percent by the year 2000, will require adjustment in type of products and their manufacture to make the best use of the raw material supply. Knowledge of the quality, characteristics, and utility of wood of a wide range of tree species will provide industry with fundamental information for use in making these adjustments through modification of present products and in development of new products to meet greater serviceability requirements and consumer needs and wants. Research to improve utilization of forest products can lead to establishment of new industry and general economic growth and development of areas of poverty and unemployment in forested areas where economic incentive is needed to encourage improved management of timber stands.

USDA and Cooperative Program

The overall objective of the Department's continuing program of forest products utilization research is to provide a sound technical basis for using the Nation's timber resources fully, efficiently, and economically in products that afford the greatest possible consumer benefits.

Research is conducted at the Forest Products Laboratory, all eight Forest Experiment Stations, and the Institute of Tropical Forestry, in cooperation with various schools, Federal and State government agencies, private industry, and professional societies. Included is a comprehensive program of basic and applied research in wood product and process development, wood fiber and chemical product development, and development

of engineered wood structures and applications to attain greatly increased efficiency in the use of wood and wood-base materials.

Also included are studies of the quality, characteristics, and utility of wood of a wide range of tree species; effect of environmental factors such as heat, light, and moisture on wood and wood products in use; effective treatments to protect wood in use from fire, fungi, insects, sunlight, high temperatures, and widely changing environmental conditions.

Research is being conducted under Forest Service grants at the Yale University School of Forestry on variation in the cell wall density of wood; at the University of Minnesota on the effect of swelling of wood on its permeability; at the State University of New York on the chemistry and ultrastructure of reaction wood; and at the University of Arizona on the free radical studies of lignin and related model compounds. A pioneering research unit at the Forest Products Laboratory, Madison, Wisconsin, is conducting research on lignin chemistry. The total Forest Service effort in forest products utilization research in the United States amounts to about 160 scientific man-years annually.

A program of research is also carried on under Public Law 480 in India, Pakistan, and Peru, involving eight projects and about 32 man-years annually.

Program of State Experiment Stations and Schools of Forestry

A total of 72.0 scientist man-years is devoted to this area of research.

Progress--USDA and Cooperative Programs

1. Wood structure and quality relations

a. Lumber grade recovery and value determination. Research on western softwood timber quality standards led to the development of a computer program for calculating the lumber volume and value yield of each log and summarizing the information by trees and stands, based on lumber grade recovery studies. The program also accounts for the cubic volume of wood in each log distributed by lumber, sawdust, and chippable residue. Such a program will be useful for a variety of forestry applications, including research data analyses, timber appraisals, and sawmill processing operations.

Other research showed that it is possible to improve the utilization of hardwood lumber with the use of an electronic computer when the size of defect-free cuttings to be produced can be specified. The computer program developed in this research prescribes how to cut each board for maximum yield of cuttings and locates the saw cuts. An actual test was made at a commerical wood-using plant, using No. 2 Common hard maple

lumber, to compare yields predicted by the use of the computer program with those obtained in actual practice. The results showed that the predicted yield was within 1 percent of the actual yield. This computer program makes possible the selection of the most economical lumber grades to produce specific parts at the lowest unit cost. Average annual savings to the industry, resulting from increased use of lower grades of lumber and from an increase of about 5 percent in the yield of defect-free parts, is estimated to be $10 million.

b. Effects of elevated temperatures on wood cells. This research, utilizing the electron microscope, showed that after heat treatment at elevated temperatures, the warty layer, pits, and pit membrance of Fagus grandifolia and Fagus sylvatica are temperature-sensitive, although the critical temperature is still to be determined. This sensitivity may be linked only to a change from a solid to a liquid state, and visual indications support such a tenent.

The study further showed that the lignin, the bonding agent in wood, melts at temperatures of 200° -240° C., and that the cellulosic structure appears unaffected. During any stress, be it the action of pathogenic fungi or excessive heat, it may be justly considered that the lignin is first to undergo change. Present fire-retardant chemicals are largely selected on the basis of the protection they afford the cellulosic constituents of wood. On the basis of this research, it might be profitable to explore chemicals that inhibit the observed changes in lignin. Chemicals having such properties, alone or in combination with others, might prove more effective in modifying the pyrolysis and combustion processes of wood.

c. Heartwood stain in red oak. Research on the properties and ultrastructure of stained red oak heartwood showed that the stain moves from ray parenchyma to adjoining elements through pit membranes and plasmodesmata. Openings in the pit membranes were not previously reported. They may facilitate the movement of materials through a specialized filamentous structure. The discovery of pores in the membrane of hardwood pits will result in additional benefits in the fields of drying, and preservative and fire-retardant treating. The research also showed that wood containing brown heart or mineral stain is most susceptible to surface checking and honeycombing during air drying. This condition is apparently due to the flow or diffusion of the staining compounds which may block the pits and obstruct the movement of moisture.

These findings will provide a basis for evaluating stains in oak which differ in physical and chemical properties and may make possible the identification of standing trees that contain stain. This knowledge will be a valuable tool for timber survey stumpage appraisal.

2. Solid wood processes and products development

a. High-temperature drying of lumber. Research on drying wood at high temperatures showed that lodgepole pine and western larch can be successfully dried in approximately one-fourth the time required by drying with present commercial time-temperature schedules. In this research "high temperature drying" was accomplished in commercial dry kilns in which the dry-bulb temperature was maintained above the boiling point of water. The study showed that the quality of drying and the uniformity of moisture content could be improved by slightly longer drying periods than used in the research for western larch, and if equalization periods were incorporated in the time-temperature schedules for both species. This research will benefit industry by providing information on how to drastically shorten kiln-drying time and thereby reduce the cost of producing dry lumber. Reduction in costs will also result from lower lumber inventories required at plants using a faster drying process. The success of these experiments has rapidly increased the demand for commercial kilns operating in the high-temperature range.

Other research concerning not only the drying of wood at high temperatures but also at pressures above atmospheric showed that thermal degradation and resultant visible drying effects were more prevalent at the higher pressures. However, observations of the phenomena indicate the possibility of modifying the mechanism of drying or the properties of wood through drying at elevated temperatures and at pressures above atmospheric to attain improved and more rapid drying techniques for the wood industry. This research provided a better understanding of the mechanism of drying and also showed that the phenomena may be useful to alter the physical and mechanical properties or the permeability of wood in connection with pressure treatments of preservation and fire retardants.

b. Particle boards for exterior use. Particle board has many potential exterior applications, particularly in the housing field, where it would be subjected to outdoor weathering. If the product is to satisfy the demands of this market, it must have resistance to degradation from exterior cyclic changes in moisture content. Research on developing a particle board having this resistance showed that treatments after pressing, combined with particles having a high slenderness ratio and a species having small longitudinal movement, were the most promising modifications. These modifications can be used for producing particle board with dimensional performance comparable with plywood and surface characteristics like hardboards. For example, surface treatments after pressing such as paint, paper overlays, and water repellents were effective in increasing the resistance of particle board to degradation due to weathering. The research will be useful to the industry in developing new type exterior particle boards to meet consumer demands and needs.

c. Improved quality of veneer. Experimental cutting of veneer to improve quality showed large differences in the quality of southern pine veneer cut with the same lathe settings. Further research showed that such differences can be caused by bacterial action that occurs in the sapwood during storage of southern pine logs in ponds or under water sprays. The experiments showed for the first time that wood attacked by bacteria has different veneer-cutting properties than wood not attacked by bacteria. Of even greater importance is the fact that wood attacked by bacteria has greater permeability which, in turn, could significantly affect drying and gluing of the veneer. This knowledge will help the southern pine plywood industry produce a more uniform product.

Meanwhile, research on heating blocks before cutting to improve veneer quality showed that heating southern pine bolts to 140° - 160° before cutting into veneer resulted in improved quality of veneer as well as other advantages. For example, heating will reduce wear of the knife and roller bar and improve the veneer quality primarily by reducing handling splits. On the basis of this research a recommendation was made to industry on the benefits of heating southern pine veneer bolts before cutting into veneer. The results will assist manufacturers to consistently make high quality veneer.

Further research on veneer cutting dealing with the setting of the pressure bar to the knife edge showed that veneer quality can be improved by using optimum roller-bar openings. Of significance was the finding that the optimum roller-bar openings in cutting yellow poplar were smaller than those for cutting southern pine. High-speed movies used in the research showed splitting ahead of the knife was more common when cutting southern pine than when cutting yellow poplar with the same setting. The work further showed that continuous measurement of knife deflections and loads on the roller bar can be used to improve the veneer cutting process. The research will help the industry produce more uniform veneer to improve the quality of the 13 billion square feet of softwood plywood and 1 billion square feet of hardwood plywood produced annually in the United States.

d. Patented saw blade reduces waste. Research on finding ways of reducing waste products resulting from cutting logs into lumber has developed a thinner kerf (width of cutting path made by the saw) saw blade than current conventional saw blades. Traditionally, saws have always had a rather wide saw kerf and little effort has ever been expended to develop thinner kerfs even though a substantial savings in volume of sawdust can be realized for each 1/32 inch decrease in saw kerf. The Forest Service Taper-Tension Saw on which letters of Patent were granted encompasses a 30 percent narrower saw kerf than is commonly used in the industry, and has a high degree of sawing accuracy over a wide operational range. The adoption of this saw by the sawmilling industry can result in an annual increase in recovery of solid lumber products valued in excess of $40 million and thereby help close the timber gap anticipated in the year 2000.

e. Improved durability of clear finishes for wood. A study on the role of wood and the effect of sunlight on the early failure of clear finishes showed that destruction of both the finish and the wood surface by ultraviolet radiation in sunlight causes the early failure of the finish. One of the mechanisms of this destructive action on wood by sunlight is the formation of free radicals in wood. The existence of free radicals was uncovered by electron spin resonance spectroscopy. The free radicals then react with oxygen to form degradation products. The research showed how the extent of such degradation could be measured and thereby permitting comparison between different species. For example, redwood was found to degrade faster than yellow poplar, which in turn degrades faster than Douglas-fir. These experiments led to the discovery that treatment of wood surfaces with an ultraviolet light absorber, dibnzoyl resorcinal, significantly reduced the quantities of degradation products formed. This discovery further led to the development of several experimental finishing systems having improved durability. These finishes are currently under test at various exposure locations in the United States.

f. Machine-driving of wood highway guardrail posts. Wood is an excellent guardrail post material with strength, cost, and service-life advantages over other materials. However, wood is not often used for highway posts in new construction because contractors perfer posts of competing materials that can be driven 2-1/2 to 3 times as fast as wood posts can be set by hand. Research conducted in cooperation with a guardrail subcontractor and equipment manufacturer developed a mobile post driver that can drive wood posts as readily as posts of competing materials. The research showed that wooden posts can be installed at rates competitive with posts of competing materials and at less cost. Savings of $1 to $2 over the cost of handsetting wood and $1 to $3.25 over posts of competing materials were indicated. Installation rates of 28 to 30 posts per hour can be expected on average sites. On difficult sites, the rates will be less. For example, on one difficult site, where posts of competing materials could not be driven nor could an auger be used, wood posts were driven at rates of 15 to 17 posts per hour. The driving tests showed that posts with blunt bottoms drive better than those with slopes, and that the driving action causes no damage to the tops of properly machined wooden posts. These findings will also benefit the wood industry by providing added outlets for wood posts in the expanding highway construction field.

g. Straight studs from southern pine cordwood. Research has developed a process for converting 4-foot southern pine cordwood into 8-foot 2 by 4's of Southern Pine Inspection Bureau "Stud" grade or better. The process features finger-jointed and glued 4-foot sections from which all drying distortion has been removed. The studs are lighter, straighter, and more easily nailed than the denser southern pine studs to which the trade is accustomed. The process is timely as it will benefit the wood industry and landowners of millions of acres of pine plantations with trees now reaching diameters from 5 to 8 inches. The experiments showed

that the studs are competitive in strength with studs made from some western species and are more than strong enough for their purpose. The research also showed that the process is economically feasible. For example, a single plant would have an annual profit from 174,000 cords of boltwood before taxes of $661,000. This is a 16½ percent profit based on a total investment of $4 million, and assuming a production of 55,890,000 board feet of studs, 50,301 tons of pulp chips, 64,638 tons of dry shavings, and 21,141 cords of bolts upgraded to a peeler grade.

3. Pulp and paper products and processes development

a. Sanitary tissue and toweling from Appalachian woods. Pulping and papermaking experiments were successful in demonstrating the suitability of a mixture of 80 percent Appalachian hardwood and 20 percent Appalachian softwood for high quality facial tissue, toilet tissue, and toweling. Facial tissue was comparable to commercial grades in brightness, strength, softness, and absorbency. Toilet tissue had higher strength and absorbency but was less soft than commercial grades. Softness, however, could be improved at a sacrifice of some of the excess strength. Toweling had equal absorbency, higher wet and dry tensile strength, and slightly lower softness than commercial products on the market. The pulp used to make these papers was produced by low yield kraft pulping digestions. These experiments provided basic knowledge that would be needed to encourage the use of Appalachian woods by prospective mills that could be located where there are large quantities of hardwoods not now being utilized and close to large markets. For example, a single 500-ton sanitary papermill using at least 50 percent hardwoods would utilize about 500 cords of hardwood per day. The mill would provide employment for about 1,000 people producing products having a total value of at least $100,000 per day.

b. Improved pulping processes for southern pine. Strong new possibilities of using southern pine to make several different paper products have been raised by research with magnesium bisulfite pulping of the species. Conventional nonalkaline processes such as the usual sulfite processes have not been successful with southern pine because extractives in the wood usually decompose the cooking liquor before digestion is completed. High quality bleached and unbleached pulps made by the new process make as good or better than typical commerical products including two-ply linerboard, offset book paper, book coating base paper, bond, toweling, and facial and toilet tissues. The usual trouble encountered on the paper machine with pitch from southern pines cooked by nonalkaline processes can be overcome by storing the logs for several months before processing. Even though the long storage of wood caused blue stain, the brightness of the unbleached pulp was significantly higher than that of kraft paper, and was further improved by treatment with a brightening agent. Fully bleached pulp can be produced with three stages of conventional bleaching whereas kraft pulps require five-stage bleaching.

A potential application for the light colored unbleached or semibleached bisulfite pulp might be in the top sheet of kraft linerboard, since there is an increasing trend toward improving the appearance of this product. Low bleaching cost and the fact that the cost of recovery of heat and chemicals will make this process especially attractive to small pulp plants. A saving of $15 per ton in production cost would be possible over the conventional kraft process for pulps suitable for making book, bond, toweling, and and tissue papers. Assuming a potential demand for this type of pulp in the South of 300,000 tons annually the saving would be $4.5 million in production costs.

4. Chemistry of wood

a. Wood carbohydrates. Research on the relationships between some uronic acids, which are important constituents of wood carbohydrates, and their decarboxylation products showed that reacting solutions of 2-furaldehyde, reductic acid, and 5-formyl-2-furoic acid, under conditions for their formation from uronic acid, are not interconvertable and are essentially end products in the reaction. The research further showed the D-galacturonic acid was the best source of reductic acid, giving yields of 10 percent of theoretical and above.

This research on the reaction mechanisms of their chemical conversion is essential to the more complete use of wood carbohydrates. The work will lead hopefully to the development of chemical processes for modifying polymer structures. It is thought that such processes will be more economical in modifying wood residue carbohydrates to have an acceptable level of digestibility for animal feed than current delignification of residues by conventional pulping methods. Thus the carbohydrates of whole wood residues would be available to ruminants as a high energy food source to replace cereal grains that will need to be diverted in the future to human consumption.

b. Bark extractives. Studies on the chemical nature and constituents of bark yielded important fundamental information. For example, a great number of chemicals have been separated and identified from softwood barks. Among them are 15 new representatives of the class of triterpenes, a widely distributed class of natural products. One of the new chemicals recently isolated from jack pine bark is a new diterpene with a labdane skeleton. The known epimer, manoyl oxide, not previously found in pine was also isolated. These findings will benefit chemotaxonomy and the biochemistry of bark. Also, the new chemicals discovered by this research as well as other chemicals yet to be discovered could be the basis for expanded markets for the large volumes of bark which accumulates at wood processing and pulp and paper plants.

c. Lignin. The complex picture structure that is slowly emerging from long and patient research, though still incomplete, shows that this plentiful but largely discarded component of wood can eventually be put to large-scale valuable uses. One of the encouraging developments has been the

discovery that many different parts of the massive lignin molecule are held together at certain junctures by relatively weak bonds, such as ether linkages. These bonds yield readily to certain treatments, notably acid or alkaline hydrolysis. Conventional pulping processes break these linkages. Unfortunately, some stronger bonds are substituted as a result of condensation reactions that accompany pulping. Consequently, the chemical makeup of lignin is radically changed by the time it emerges from the pulp digester. This greatly complicates the chemist's task of identifying the altered chemical structure and devising means of converting it to useful products.

Research to aid the chemist in this task, involving gas-liquid chromatographic analysis of phenols from lignin, provided a reliable analytical tool for use in studies on chemical degradations of lignin that will lead to mixtures of simple phenols. The research was successful in achieving efficient quantitative separations and determinations of the trimethylsily ethers of guaiacols and catechols derived from alkaline degradation of lignins from kraft and sulfite pulping. The method will be especially useful for determining the economic value of chemical processes.

d. Chemical composition of compression wood and bark. A study of the chemical composition of normal and compression wood and bark in 14 conifers showed that compression wood differed throughout from normal wood in its higher lignin content, which ranged from 37 to 41 percent, its low content of cellulose, which was only 30 to 32 percent, and in containing 7 to 12 percent of galactose residues. The research further showed that unlike the wood, normal and compression bark did not differ chemically. The results indicate that all confiers form compression wood of identical chemical composition. This research will provide fundamental information for application in the development of economical commercial chemical products and processes.

Other research on the isolation and characterization of a galactan from compression wood of red spruce showed that water extraction gave a low yield of galactan, however, a considerable amount of the galactan was easily removed from the wood in the course of the delignification, irrespective of the procedure employed. The research was also successful in developing methods for isolation of uniform galactans, free from xylan and galactoglucomannan and homogeneous on free boundard electrophoresis.

e. Interaction of wood with polymeric materials. With the ever-increasing diversification and uses for wood products, better understanding of the properties of wood surfaces becomes increasingly important for paintability, weatherability, gluability, and treatability. A knowledge of the size of voids in green wood substance may well be the key to more successful modification of wood products by impregnation. Research on the interaction of wood with polymeric materials showed that the submicroscopic void size in green wood substance could be measured by determining the maximum molecular size of a waterborne solute that could penetrate the wood substance. The procedure was based on a study of the penetration or non-penetration into green wood substance of polyethylene glycols of various

molecular weights in aqueous solutions. The effective size of the void was found to be the size of the polyethylene glycol-3000 molecule. This procedure could also be used to determine the size of voids in delignified wood and wood decayed by enzymes.

The research provides another approach to studying the physical aspects of pulping (delignification), which is an important phase of the fastest growing segments of the forest-based industry. According to these findings, it is probable that lignin must be degraded to the dimensions of these voids before effective delignification can be accomplished.

5. Serviceability of wood products in use

a. Fire endurance of wood. Research on surface flammability of plywood showed that overall flame-spread resistance of thin plywood panels could be improved by placing noncombustible inserts immediately below the face veneers. The tests showed that 1/32-inch asbestos or aluminum sheets employed with thin face veneer and panel constructions significantly reduced surface flammability. Also, experiments with Douglas-fir plywood in 1/4- to 1-inch thicknesses indicated that thin panels have the same flame-spread resistance as thick panels. This research will help increase the marketability of panel products in construction projects such as in apartment rehabilitation and in other housing projects where the use of panel products was prohibited due to the mistaken concern that plywood is more flammable when used in thin sheets.

Meanwhile research on the charring rate of wood to develop data needed for designing and predicting fire endurance of heavy timber construction showed that fire intensity, species, specific gravity, moisture content, and grain orientation are related to the charring rates for wood. These findings further illustrate wood's unique ability to insulate itself against heat as it chars during combustion. The importance of this phenomenon has long been generally recognized among builders, underwriters, and code authorities. The experiments with three species, Douglas-fir, southern pine, and white oak specimens at four moisture content levels, showed that the critical char-formation temperature for all three species was 550°F. The standard charring rate of 1/40 inch per minute or 1-1/2 inches per hour was found to apply to Douglas-fir of average specific gravity and 10 percent moisture content. In general, woods of higher moisture content and specific gravity char more slowly.

b. Color changes in wood exposed to sunlight. Previous studies have shown that the primary factor affecting the color changes in wood is ultraviolet light. Recently research led to the discovery that air, oxygen, nitrogen, and argon each have a different coloring effect on wood subjected to intense ultraviolet light. When ultraviolet light was used to stimulate the reaction, both redwood and birch samples darkened during the first several hours of exposure to atmospheric gases. After initial darkening, wood exposed in oxygen and air stopped darkening and became lighter.

However, wood exposed in nitrogen and argon continued to darken through the exposure period. This research clearly showed the complex nature of the color change and suggests further study of the factors contributing to the coloring reaction. Once these factors are known and understood, finishing systems can be developed to halt or control the process and thereby provide the consumer with an improved means for naturally finishing wood for both exterior sidings and interior products.

c. A new device for measuring moisture content of wood in use. Past research has shown that wood shrinks and swells as its moisture content changes. Problems that result from this phenomenon cost the consumer about $110 million per year. Recent research to reduce this cost is concerned with the establishment of the moisture content requirements of wood in today's houses and buildings. This research has developed an extremely useful, simple, inexpensive probe for determining moisture content of a wood product in use. The probe can be easily made from a strip of wood coated on two opposite faces with conductive silver paint. It can be used at moderate temperature, at high and low moisture conditions, and for determining average atmospheric moisture conditions. Also, the probe shows promise of being useful for wood-moisture measurements in kiln drying, high-temperature drying, fire testing, paint studies, and investigations of low-temperature environments where moisture amounts and changes are of major significance. This development will permit more comprehensive moisture content studies on how moisture problems can be efficiently reduced to give improved service to wood products.

6. Wood strength and structural concepts

a. Strength grading of southern pine dimension lumber. Research to pinpoint the performance of visual grading of southern pine lumber showed that visual grading is only 48 percent efficient--that is, the lumber is so graded that on the average only about half its load carrying capacity can be safely utilized--for bending uses and 43 percent efficient for compression. This inefficiency arises because many pieces in a grade are well above the stress ratings for the grade. They are only partly offset by a few pieces that fall below the assigned values. These results show that visual grading, to provide for average quality material, cannot discriminate closely enough between weak and strong pieces. The experiments further showed that machine performance grading of structural dimension lumber on the basis of a flatwise stiffness determination and associated fiber strength capability of the lumber was 50 percent efficient for bending uses and 73 percent efficient for compression. The research will also provide information on actual strength properties of commerically produced southern pine dimension lumber for use in arriving at and assigning design stresses. This will result in more reliable design values for the 3.2 billion board feet of southern pine lumber produced annually. Therefore, the potential savings to the industry would be in the millions of dollars annually if grading efficiency could be increased even 1 percent over the present grading efficiency of current methods, either visual or mechanical.

b. Improving performance of trussed rafters. Past experience has shown that trussed rafters installed in a building are subjected to many conditions that affect the load-carrying capacity of the joints. For example, changes in relative humidity and temperature cause dimensional changes in truss members resulting in loosening of the connector; cyclic live-loading, resulting from changes in the amount of snow or wind pressure on the roof cause the joints to "work" and thus alter their performance; or a constant load, such as a dead load, causes creep. Current research to determine the actual effect of these conditions on the design of improved wood trussed rafter joints showed that moisture-cycled specimens had from 1 to 3-1/2 times more elongation or deflection than the control specimens. The experiments also showed that losses in maximum load for the cycled specimens ranged from 0 to 30 percent greater than for the specimens not cycled. High initial moisture content of the material used to fabricate the joints had a significant effect on the elongation and deflection of the mechanically fastened joints but did not cause a decrease in maximum load capacity, with the exception of the barbed metal-plate joints where shrinkage caused the plates to bow, thus removing the barbs from the wood and loosening the joint. For glued joints, however, the tests showed that wet material used in fabrication caused a reduction in maximum load capacity.

This research will benefit industry by providing basic knowledge essential to the design of improved trussed rafter joints to insure their satisfactory long-time performance under varying conditons of loading, moisture content, and moisture cycling. Also basic knowledge such as developed in this research, of performance of trussed rafters, a product for which an estimated $250 million is spent annually, is essential to predictions of long-time performance for existing housing and light-frame construction. The use of reliable techniques and methods to minimize the effects of initial moisture content and moisture cycling under load will save property owners millions of dollars annually because of reduced maintenance costs and longer property life.

c. Strength of large glued laminated beams. Since laminated beams 5 feet and more in depth and over 100 feet long are now commonly made, it becomes increasingly important to insure that design procedures used are correct. Research on strength-depth relationship in wood beams developed a new design theory, based on a "weakest link" concept. This theory was verified with bending tests of laminated beams 50 feet long and 31-1/2 inches deep. Predicted loads were within 2 percent of the loads obtained on beams made of clear lumber. This research showed that an increase in depth or an increase in length will cause a decrease in average modulus of rupture and standard deviation of modulus of rupture of wood beams. Tests of similar beams made of the lowest laminating grade of Douglas-fir failed in tensile laminations at only 55 to 78 percent of the design load as calculated by the old formula based on the ratio of knotty to gross cross section. Consequently, the need for closer assessment of the effects of knots and crossgrain was shown. Further research showed that beams made of knotty lumber can carry markedly

higher loads if the outermost tensile lamination if made of clear, straight-grained lumber. The results of this research will benefit industry and the consumer by providing new design procedures for size effect thereby focusing attention on the increased potential uses of wood beams in wood construction.

d. New methods for attaching wood panels to walls. A fast, economical, new method of attaching plywood paneling to existing interior walls has been developed by research involving uses of wood in apartment rehabilitation projects. The panel system, called "Fur-Lok," was recently installed at an on-site demonstration in a New York tenement building scheduled for renovation. Using the system for the first time, two carpenters paneled an 8- by 17-foot room, including framing around 2 doors and 3 windows, in 3 hours and 23 minutes. With experience, this time could be cut by more than an hour. Speed of installation is of primary importance for products used in a recently developed 48-hour method of apartment rehabilitation that will displace the occupants for a minimum of time. The success of the panel system is due to a novel locking-wedge--one wedge is attached to the panel and one is attached to the existing wall--that eliminates the need for nailing the panels to the furring strips. The research showed the Fur-Lok system fits in well with the concept of "instant rehabilitation," and will not only help the plywood industry capture its share of a market that will call for 2.3 billion square feet of new walls in New York City alone, but will also play a part in providing decent housing for families currently living in the tenements.

e. Improving stacking strength of corrugated containers. Research on improving stacking strength of corrugated shipping containers on pallets showed that vertical alignment of containers--that is, each container is aligned with the one below--and a simple device called a slip pad, increased the stability and strength of boxes of palletized loads by as much as 65 percent. A slip pad consists of a sheet of corrugated fiberboard which is placed between the layers of containers on a pallet. The experiments showed that slip pads tied the load together and helped distribute the compressive forces over adjacent containers when the boxes were not perfectly aligned. The results will help the industry reduce the considerable loss and damage resulting during shipping and storage of palletized loads. Also, savings to shippers will result from a reduction in the grade of boxes required to carry the same load as before slip pads were used.

f. Characteristics of salt-treated wood. Research on the effect of chemical treatment on physical properties of ponderosa pine and red oak showed that the wood swelled greater in chemically treated wood than in matching specimens of untreated wood. Only sodium chloride showed an appreciable effect on the dimensional stability of the two species as measured by volumeric shrinkage and swelling. However, treatment with the various chemicals increased the anisotropic swelling characteristics of both species. The experiments further showed that equilibrium moisture content values were substantially increased by treatments with ammonium sulfate, sodium chloride, and zinc chloride. Treatment with two phosphate salts had no apparent effect on

equilibrium moisture content, while treatment with borax and boric acid caused increases in moisture content that are not considered permanent. This research will benefit industry by providing fundamental information for use in formulating impregnents for wood to meet specific performance requirements specified in building codes, building specifications, and insurance regulations.

7. P.L. 480 Research

Investigations in India on the variations in fiber characteristics in Pinus roxburghii showed that fibril angle is closely related to rate of growth since it was distinctly smaller in the slower grown latewood. Also tangential diameter and tangential wall thickness shows less seasonal variation than radial diameter and radial wall thickness and may therefore prove more useful for purposes of comparison. All characters studied showed less variation within the earlywood or latewood than in the entire growth ring.

Other research in India on the effect of pre-steaming and pre-boiling on water or moisture movement, drying rates and degrade in seasoning of sal (Shorea robusta) showed that initial cracking developed during pre-steaming but it was completely avoided in pre-boiling. Also the study showed that steamed and boiled material dried considerably faster and suffered less severe degrade than untreated material under air seasoning as well as under controlled kiln drying conditions. Comparative examination of anatomical structure of sal before and after steaming and boiling showed no appreciable change which could account for difference in seasoning behavior.

Possibilities of chemical seasoning of axlewood (Anogeissus latifolia) were also investigated. It was found absorption of chemical into the wood is limited and tensile stresses developed in the surface layer were not reduced at this absorption rate as compared to the untreated material.

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B. FOREST ENGINEERING RESEARCH

Problem

Forestry operations in the United States, and in the world in general, have not kept pace with other basic industries in improving labor output, in mechanization and automation for improved efficiency, and in reducing the physical drudgery involved. Man-strength hand operations still retard realization of an industrial revolution in most woods operations. Mechanization comparable to that achieved in American agriculture is sorely needed.

The forest industries are, historically, decentralized. There are many woodland owners, contract loggers, mill operators, equipment manufacturers, and sales organizations, each concerned with their individual problems. Equipment manufacturers, generally, have done a remarkeable job in producing the machinery used in today's operations considering that they have been able to attack only subelements of overall systems without adequate engineering guidance from the purchaser. Neither the purchaser nor the manufacturer has been staffed to analyze the whole program and specify operational goals.

Small studies to support piecemeal improvements will never lead to the major goals required--giant steps in cost reduction and improvement of forestry operations.

Not only have the forest industries lagged in mechanization and improved efficiency, they are now beset by increasing restrictions due to competing forest interests, such as recreation, water, wildlife, and livestock uses which tend to increase the already high costs. There has been relatively little systematic research of how diverse elements of forestry operations, including harvesting, fit together--or how they affect other values such as soil, water, aesthetics, etc.

The constant price squeeze on wood products in the marketplace requires more efficient bulk collection methods for harvesting and delivery of raw material to processing plants. New systems of logging are needed for harvesting of lower valued timber, for operations in more difficult access areas, and for operations in areas with multiple use constraints.

In the East and South the demand for pulpwood is increasing currently at nearly 11 million cords per year. To meet this increased demand with today's mechanization will require about 56,000 more workers per year in an industry where it is already difficult to obtain labor and maintain current production. Radically improved worker productivity is urgently needed through mechanization and more efficient systems of operation.

In the West conventional logging and road building in steep terrain and on critical soils tend to increase soil erosion, landslides, and flood damage. These operations are frequently incompatible with landscape and recreation values. It is estimated that over 26.0 million acres of commercial forest

land in western United States cannot be logged under current methods. New systems of harvesting to permit access to difficult terrain and to protect water, soil, and aesthetic values are needed.

Research is urgently needed to establish the engineering operational criteria for forestry operations and to develop the concepts required to perform them economically and in accordance with good land usage. The program is geared directly to the goals of increased supplies and lower costs set for the USDA National Program of Research.

USDA and Cooperative Programs

Five problem areas in United States forestry have been selected for research attack. These problem areas characterize engineering obstacles to, or opportunities for, achievement of forestry and land management objectives in large segments of United States forestry. These areas can best be described as complexes having special problems or opportunities created by interrelated factors such as timber values, markets, accessibility, silvicultural requirements, watershed and recreation needs, current or potential industrialization, degree of mechanization, terrain and weather. The areas have been selected on the basis of combinations of factors which create a problem or situation.

An engineering research program has been established for each forestry problem complex in the geographical area of the country where the problem is dominant. These programs are located on or close to college or university campuses and operate in close cooperation with the engineering schools and with other disciplines in the institution.

The program is designed to improve the efficiency and performance of forestry operations through the application of systems engineering. Systems analysis makes it possible to proceed with experimental hardware and prototype testing with considerable confidence. This technique also reduces the time required, hazards and costs of experimentation, and improves the returns therefrom.

The program is directed particularly to original applications designed to revolutionize forest production, protection, and utilization operations while considering other multiple use requirements.

Close liaison is maintained with other domestic and foreign agencies engaged in forestry equipment research and development, and with equipment manufacturing industries and defense laboratories.

Research is underway in the following problem areas:

1. Steep, erosible mountain slopes with small stemmed timber of relatively low value.--The problem is characteristic in the lodgepole pine forests of the Rocky Mountain region of the United States but similar conditions exist elsewhere, particularly in the western United States. The research program is located at Bozeman, Montana, and operates in cooperation with Montana State College. Current effort 3 SMY's.

2. Intensive forest management complex.--The problem is characteristic of forests in the South and involves mechanization of the "timber factory" production from "pollen to product," reduction of excessive hand labor in current methods to meet requirements of an ever-diminishing labor supply for forest work. The research program is located at Auburn, Alabama, and operates in cooperation with Auburn University. Current effort 3 SMY's.

3. Deteriorated northern hardwood stands.--The problem is characteristic in the hardwood forests of the Great Lakes area, but similar conditions exist in the Northeast and to a limited extent in the South and Southeast, and involves the removal of current low value stands without economic loss and preferably at a profit, preparation of site for replanting to improved species, and planting of new stock. The research program is located at Houghton, Michigan, and operates in cooperation with Michigan Technological University. Current effort 2 SMY's.

4. Virgin timber types with heavy logging debris, difficult access, high road construction costs.--The problem is characteristic of the forests of the Pacific Northwest and Alaska, but similar conditions may be found in California, and inland areas of the West. The research program is located in Seattle, Washington, and operates in cooperation with the University of Washington. Current effort 3 SMY's.

5. Large volumes of low value hardwoods on steep slopes, low densities per acre and interspersed with some high value hardwoods, most stands in small ownership patterns.--The problem is found typically in the Appalachian area of the eastern United States. The research program is located in Morgantown, West Virginia, and operates in cooperation with West Virginia University. Current effort 3 SMY's.

The Federal scientific effort devoted to research in this area totals 11 SMY's intramural and 4.5 SMY's extramural, all in the Engineering field.

Targets for the next 5-year period are:

1. Complete design of a workable balloon logging system to permit harvest of inaccessible timber.

2. Develop skyline logging systems for thinnings and partial cuts in difficult access areas.

3. Conduct pilot line tests of a woodchip pipeline to confirm laboratory results and demonstrate systems features to industry.

4. Develop design and/or performance criteria for engineered harvesting systems for Rocky Mountain forests.

5. Complete design of mechanized system of harvesting gum naval stores.

6. Develop design and/or performance criteria for engineered harvesting systems for southern forests.

7. Develop design and/or performance criteria for engineered harvesting systems for Appalachia.

8. Develop design and/or performance criteria for engineered harvesting systems for northern hardwoods (Lake States area).

Program of State Experiment Stations and Schools of Forestry

A total of 3.2 scientist man-years is devoted to this area of research.

Progress--USDA and Cooperative Programs

1. Systems for steep erosible mountain slopes (Rocky Mountain)

a. Transportation Systems. A start has been made on a systematic program of research investigation in the area of wild land transportation system. A problem analysis is being prepared to guide increased efforts in this area with special emphasis on road location and construction on steep erosible soils.

b. Woodchip Pipelines. Active planning has begun on installations of a pilot woodchip pipeline (probably in western Montana) to confirm laboratory and analytical results and demonstrate feasibility to industry. Interest is very keen in the equipment and forest industries.

2. Systems for deteriorated northern hardwoods

Cross-cut shears can be used for felling, bucking, limbing, etc., and industry is interested in exploiting this concept to the fullest but little information is available on force, energy, and mechanics of the method. Equations for estimating cross-cut shearing forces for five species (white spruce, aspen, eastern hemlock, yellow birch, hard maple) are now available at the Houghton project from measurements made on various combinations of knife thickness, level, cutting speed, and dullness.

3. Harvesting systems for difficult access

Two National Forest engineers have been "graduated" from a one year's training assignment in systems engineering and aerial logging systems design at the Seattle project. Plans are now underway to increase the number of trainees to four. Symposium and special training sessions have been conducted for Region 6 National Forest engineering and timber management personnel on designs and layout of skyline systems for inaccessible sale areas. Research results are getting into use with a minimum of delay and should provide an early increase in the available allowable cut in many difficult access areas.

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V. FOREST ECONOMICS AND MARKETING RESEARCH

A. FOREST SURVEY

Problem

Accurate and up-to-date information on the Nation's present and prospective timber resources is needed as a basis for judging the adequacy of existing forest policies and programs, the nature and magnitude of timber supply problems, and opportunities for industrial investments in forest products manufacturing facilities. The Forest Survey is the only source of such comprehensive nationwide data on timber resources. It provides basic information on the area and condition of forest lands by various classes of ownership; the volume, quality, and location of standing timber; trends in timber growth and mortality; amount and kind of timber cut for industrial and other products; and the prospective availability of future timber supplies.

Because of rising demands for timber, rapid changes in timber cut and growth, and increasing competition for land, there is an urgent need for (a) acceleration of the Survey to provide up-to-date appraisals of the timber situation, and (b) intensification of the Survey to provide more localized information needed by public and private organizations in carrying out forestry programs, particularly programs concerned with forest industrial development and improvement of forest practices on small ownerships.

USDA and Cooperative Programs

The continuing program of Forest Survey research is conducted largely through the Forest Experiment Stations of the Forest Service in cooperation with State conservation agencies, wood-using industries, and other contributors of manpower and funds. This nationwide inventory covers some 760 million acres of forest land, including more than 500 million acres classed as commercial forest land. Resurveys are being made at intervals of 8 to 15 years in different States. Comprehensive studies of the Nation's forest resources and outlook for future timber supplies and demands are made on an 8 to 10 year schedule.

Forest Service effort on timber resources surveys and appraisals involves about 43 scientist man-years annually.

Program of State Experiment Stations and Schools of Forestry

A total of 12.0 scientist man-years is devoted to this area of research.

Progress--USDA and Cooperative Programs

1. Field inventories

During the past year the equivalent of approximately 48 million acres of commercial forest land was inventoried. Field surveys were conducted in Alaska, California, Indiana, Michigan, Mississippi, Montana, New York, Ohio, South Carolina, Virginia, and Washington. Reports appraising the forest situation were issued for 8 States or portions of States.

2. A third look at the timber resources in North Carolina and Minnesota

The third statewide survey of North Carolina's timber resources showed that commercial forest land has increa by almost 2 million acres since the first survey in 1938. Over this period the volume of timber increased by 3.7 billion cubic feet--a 25 percent gain. However, this increase has not been uniform by species. Softwood volume increased 8 percent while hardwood volume increased 42 percent. The increase in forest area reflected the reversion to forests of abandoned farmland. The increase in timber volume reflected improved forest management and protection, more complete utilization of the timber harvested, and a reduction in the annual volume of softwood cut. The new survey showed that timber growth now exceeds cut by over 20 percent, but the margin of growth over a rising cut is narrowing. The large proportion of low-quality timber occupying growing space is one of the major forestry problems in North Carolina.

A report on the third survey of Minnesota's timber resources indicated that timber inventories have increased 37 percent since 1953 as the State's second-growth forests have approached maturity. Though the acreage of commercial forest land is slightly below that of 1953, the growing inventory of commercial-size timber suggests that stands can support a substantially larger cut than seemed desirable a decade ago.

3. Photographic techniques for estimating insect damage in western forests reduces survey cost

Periodically forest insects kill or damage large numbers of trees in western forests. Field surveys to estimate the amount of damage and plan salvage operations are frequently extremely expensive because of the scattered and erratic nature of the outbreaks. A study in the Pacific Northwest shows that aerial photographic techniques can reduce the cost of such surveys by 25 to 50 percent. The published study contains detailed step-by-step directions for conducting surveys by a combination of special aerial photography and field checking. It lays out procedures for using aerial photos to plan and carry out salvage operations. It also recommends film types and scales, describes and illustrates by example an efficient sampling design, and presents several guidelines for use in determining if aerial photographic techniques are usable.

4. First comprehensive surveys of timber resources in New Mexico and Arizona completed

The first survey of New Mexico's timber resources indicated an inventory of about 28.3 billion board feet of sawtimber on some 6.3 million acres of commercial forest land. Cutting in 1962, mostly saw logs used in the manufacture of lumber, amounted to about 240 million board feet. The predominant commercial species in the forest is ponderosa pine (57 percent) and Douglas-fir (18 percent). About three-quarters of the sawtimber volume is publically owned. Over half of the sawtimber is old-growth, subject to a high rate of mortality.

The initial survey in Arizona showed that this State has about 4 million acres of commercial forest land, supporting some 27 billion board feet of sawtimber. Ponderosa pine composes about 85 percent of the sawtimber inventory. Ninety-six percent of the commercial forest area and 98 percent of the board-feet volume is publically owned. In 1962 about 405 million board feet of sawtimber was cut from commercial forests. About three-quarters of this volume was used in the manufacture of lumber.

5. Pulpwood production in the Northeast

The first in a series of annual reports on production of pulpwood in the Northeast presents information on round pulpwood production, pulpwood chips, and miscellaneous byproducts used in the manufacture of woodpulp in each of the 12 northeastern States. More than 4 million cords of pulpwood is being produced in these States. Maine is by far the region's largest pulpwood supplier--producing over half of the region's cut of round pulpwood. About 40 percent of all round pulpwood produced in the region is spruce and fir.

6. A system for processing forest inventory data

A new study presents a comprehensive solution to the major problem of processing large amounts of forest inventory data. A detailed manual describes several principal subsystems--EDIT, TABLE, and OUTPUT. The operative subsystems (FORTRAN IV computer programs) are designed for use with high-speed computers such as the IBM 7094/7040 Direct Coupled System. These accommodate variable format input records that may be edited, coded, augmented, and summarized in a flexible set of tables of resource statistics which are printed with appropriate sampling errors.

7. Photo identification guide for land and forest types in interior Alaska

The initial survey of the forest resources of Alaska included development of a photo guide for the identification of land and forest types in interior Alaska. This guide includes 70 stereoscopic aerial photo scenes that can be used to identify the most commonly used land and timber types.

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B. FOREST ECONOMICS

Problem

Forest Economics research programs are aimed at (1) developing criteria for the allocation of approximately $700 million now spent annually on the protection, development, and management of forests and forest lands for timber production; (2) providing management guides for integrating and balancing multiple uses of forest land to meet rapidly expanding public demands for timber, water, wildlife, recreation, and other forest related goods and services; (3) identifying the most effective programs for stimulating the millions of owners of forest tracts to follow productive management practices; and (4) determining the size and combination of forestry programs that would most effectively and cheaply supply the Nation's future demands for timber and other forest products.

USDA and Cooperative Programs

The continuing long-term program of applied forest economics research, conducted mainly through the Regional Forest Experiment Stations of the Forest Service, is closely coordinated with timber management research in studying problems of timber growing, with forest fire, disease, and insect research in appraising problems of forest protection; and with watershed, range, and recreation research in evaluation of competing and multiple uses of forest lands. Cooperation is also maintained with the Economic Research Service, State Agricultural Experiment Stations, and forestry schools.

Forest Service effort devoted to research in this field totals 25 scientist man-years annually.

Program of State Experiment Stations and Schools of Forestry

A total of 8.7 scientist man-years is devoted to this area of research.

Progress--USDA and Cooperative Programs

1. Economic guides for blister rust control in the East

A new study to develop guides and standards for blister rust control in the Northeast describes a procedure for evaluating white pine blister rust control opportunities. A method is provided for estimating timber values saved by immediate control rather than deferred control. In this procedure, the discounted values of timber saved are compared with expected control costs to determine where current control is economical.

2. A computer program for evaluating long-term forestry investments

With increasing pressures in industry and government for greater efficiency in using investment funds, and a growing number of investment alternatives generated by a rapidly changing economy, there is an expanding need for procedures for quickly evaluating investment alternatives. Use of desk calculators is too time-consuming and available computer programs have not been applicable to many common investment problems. A new program (NCRETURN) has been developed which permits quick and economical evaluations of a large number of forestry or other long-term investments. This computes discounted costs, incomes, and net worths for a range of interest rates, and internal rates of return.

3. Economic returns from private woodlands in Indiana

In recent decades many owners of small private timber tracts have been encouraged to invest labor and capital in woodland management. An investigation of the economics of management on 50 small nonindustrial holdings in Indiana showed average annual net returns per acre of woodland of about $7.00. Investments in land and timber ranged from a low of $34.00 per acre to $660 per acre, averaging about $170 per acre. The rate of return from timber management was about 6 percent on some properties and averaged about 4-1/2 percent on the woodlands studied.

4. A computer program for calculating allowable cut using the area-volume check method

Recent research in the Pacific Northwest has led to development of an "ARVOL" computer program which calculates allowable cut by the area-volume check method. Computations which formerly required at least 20 hours by hand can now be completed in less than a minute using the new computing system.

5. Logging road standards

An analyses of alternative standards for logging roads in western Oregon indicated that where limited traffic is anticipated "low design-speed" roads yield greater returns on investments than relatively expensive "access roads," despite higher maintenance and hauling costs.

6. Increasing shortages of black walnut veneer timber

As a result of growing scarcity of high-quality walnut timber and increasing demand in both domestic and export markets, prices paid for veneer quality logs have doubled in the last 10 years, and pressures have continued for export controls. In the long-run, intensive management of the timber now standing, and the establishment and management of walnut plantations, would provide increasing quantities of high-quality walnut timber.

Black walnut timber is found throughout most of eastern United States. Over one-third of the total of 2.7 billion board feet occurs in Missouri, Kentucky, and Ohio. Surveys conducted since 1960 reveal that about 10 percent of this volume is in trees over 19 inches d.b.h., while 30 percent is contained in trees 15 to 19 inches d.b.h. The annual growth of sawtimber-sized trees amounts to about 4 to 5 percent of the current inventory, or about 120 million board feet. Estimates of the annual cut in 1960 is approximately 94 million board feet--slightly less than the growth. However, when quality is considered, the annual cut of high-quality material is substantially in excess of growth.

7. Woodland owners in West Virginia

Two-thirds of the total commercial forest area in West Virginia is in private nonindustrial ownerships. A study of these ownerships indicated that three-fourths of the owners had little interest in commercial timber production. Much potential growth consequently is not being realized. West Virginia has more standing hardwood sawtimber than any other State, yet it also has problems of low timber quality, and forest land productivity considerably below potential.

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C. FOREST PRODUCTS MARKETING

Problem

In recent decades nonwood products have displaced wood in many traditional markets in construction, manufacturing, and shipping. At the same time the volume of timber available for utilization by forest products industries has been rising. Marketing research, by developing ways of reducing costs in the harvesting, processing, distribution, and consumer use, expands the markets for timber products and increases the contribution of timber resources to the Nation's economy. Through appraisals of present and prospective trends in the use of timber products, it also provides guides for marketing timber products and for the investment decisions of forest land managers and timber products manufacturers.

The basic goal of all marketing research is to increase the incomes of forest owners and timber processors while providing consumers with better products at lower prices. Special attention is currently being paid to the stimulation of forest-based industrial development in depressed areas such as Appalachia, the Rocky Mountains, and Northern Lake States.

USDA and Cooperative Programs

The continuing program of applied marketing research is conducted in part by Regional Forest Experiment Stations and in part by the Washington Office staff of the Forest Service. Close cooperation is maintained with other scientists engaged in related marketing, utilization, engineering, and economic research within the Forest Service, other public agencies and forest products industries. Cooperation is maintained with the Statistical Reporting Service, State Agricultural Experiment Stations, forestry schools, Bureau of the Census, Federal Housing Administration, various forest products and building trade associations, and others who do research or have access to data pertinent to analyses of current and prospective markets for wood and other materials. Forest owners, loggers, processors, and consumers of wood products also cooperate by supplying production and marketing data.

Forest Service effort in this area of research totals 34 scientist man-years annually.

Program of State Experiment Stations and Schools of Forestry

A total of 19.2 scientist man-years is devoted to this area of research.

Progress--USDA and Cooperative Programs

1. Rising trends in the demand for and prices of most timber products

A study of the demand and price situation for forest products revealed that consumption of industrial timber products in recent years has been substantially above the trend level projections contained in the recent Forest Service report "Timber Trends in the United States." This was caused by a rate of economic growth that has been materially in excess of the projections available at the time the Timber Trends study was made in 1963 and 1964.

The study also revealed rising trends in the prices of stumpage, logs, and most timber products and growing imports of veneer, plywood, woodpulp, and newsprint. These trends largely reflected increasing competition for the available timber and the additional capital and labor costs associated with logging the smaller sized and lower quality trees in stands that are more inaccessible or have low average volumes per acre.

2. The market for southern pine studs in Georgia house construction

In 1965 Georgia builders used over 40 million board feet of studs to frame exterior and partition walls in some 12,800 new single-family homes. Douglas-fir made up 47 percent of the total and western pine 19 percent. Southern pine accounted for only 20 percent of the market.

The primary objection to southern pine studs--cited by 93 percent of the respondents--was their lack of dimensional stability. Builders complained that they were usually too wet and warped. On the average, Georgia builders paid $24.00 more per thousand board feet to get Douglas-fir in preference to southern pine. Tighter quality control by southern pine producers would increase production costs, but this could be offset by higher prices for trouble-free studs and a bigger share of the market.

The study also revealed that Georgia builders generally preferred southern pine sills, girders, floor joists, ceiling joists, and roof rafters because of the strength, stiffness, and lower cost of southern pine. The demand for board lumber has been severely curtailed because of inplace cost advantages of sheet materials.

3. Hardwood lumber preferences of three major user groups

Furniture, flooring, and pallet manufacturers consume over 60 percent of the hardwood lumber produced in the United States. A recent survey of these manufacturers indicated that they want lumber sawed full and uniform in thickness, and accurately edged, trimmed, and graded. Furniture producers apparently were satisfied with factory grade lumber as it is commonly produced. But flooring and pallet manufacturers indicated a preference for

lumber sizes or grades that are generally not available. About 75 percent of the flooring producers indicated a desire for stock widths--multiples of 3 inches for oak flooring and 4-1/2, 6, and 9-inch widths for hard maple. Most said they would pay $2.00 to $3.00 more per thousand board feet, and a few were offering $5.00 to $6.00 more for these widths. Pallet manufacturers wanted lumber sawed to stock lengths as well as widths, and were willing to pay up to $8.00 or more premium for sound-square-edge, 4/4 and 8/4, hardwood lumber meeting their specifications.

Assuming a cost increase of not more than $2.00 per thousand board feet for production of stock sizes, and an average increase in value (price) to consumers of $4.00 per thousand board feet, the hardwood lumber industry could substantially increase its income by tailoring its production to the needs of the 2.2 billion-foot flooring and pallet market.

4. Proper air-drying practices can increase profits of lumber producers and reduce remanufacturing costs of lumber users

The efficiency of air-drying and the quality of air-dried lumber are important to both lumber producers and users. Poor air-drying practices cause seasoning defects that lower the grade and value of lumber, reduce income to lumber producers, and increase remanufacturing costs of lumber users. A study of the efficiency of commercial air-drying practices at central Appalachian sawmills found that the average loss from degrade of red oak amounted to approximately 10 percent of lumber value. The most important defects were checks and splits. Both kinds of defects occurred in lumber stacks where roofing was inadequate and where too few stickers were used. Greater degrade losses occurred at forklift-type yards than at dock-type yards, at smaller sawmills than at the larger ones, and in fall- and winter-stacked lumber than in spring- and summer-stacked lumber.

The results of this and similar studies show that significant financial losses result from poor commercial lumber drying practices. In the hardwood areas alone, application of existing research knowledge could produce an estimated net annual gain of $56 million for the lumber industry and its customers.

5. The manufactured home--an important market for wood products

A study of home manufacturers in the Central States found that most manufacturers still use wood as the basic framing material, but often use smaller wood members than are used in conventionally built houses. The average volume of wood products included in wood-frame house "packages" was 5,122 board feet of lumber, 3,334 square feet of plywood (3/8-inch basis), and 1,104 square feet (1/2-inch basis) of building board. An additional 694 board feet of lumber, 495 square feet of plywood, and 238 square feet of building board were included in garage "packages." Most of the lumber used was softwood.

6. Hardwood sawmills can increase profits by sawing dimension lumber and timbers

Most small- and medium-sized hardwood sawmills in the Appalachian area produce substantial quantities of low-grade lumber that does not pay the cost of production. Studies of hardwood sawmill operating and marketing practices have revealed that sawing planks and timbers from small logs and from cores of large logs that are the basic source of the low-grade lumber yields more volume and a higher value product at lower operating expense. Five mills studied could have increased operating margins by $2.00 to $25 per thousand feet sawed. Depending on mill size and markets, increased annual returns of from $125 to $7,500 per mill could have been realized from sawing the larger products.

7. Applying linear programming in forest industry

Firms in the timber industries process logs that vary widely in species, size, and quality and produce products that show even a broader range in size, grade, and intended use. Managers are constantly faced with the problem of determining the best choices among the input and output alternatives. A new study explains three situations in which linear programming can be a valuable guide to the decision maker. One of these examples is expanded to serve as a model for prospective users of operations research methods. Step-by-step instructions are outlined for preparing input data cards and interpreting computer output.

8. Price comparisons for pine veneer bolts, saw logs, and pulpwood

The South has a thriving new outlet for pine, the veneer bolt market. As plywood plants open up from Texas to Virginia, more and more forest managers are selling veneer bolts in addition to saw logs and pulpwood. Principles of preparing price-comparison curves for the various products are illustrated and explained in a recently completed report. The resulting charts are useful to buyers as well as sellers of timber and can be applied to any forest product.

The procedures as outlined can be used advantageously by veneer, pulp, sawmill, or stud mill managers in setting price policy. Measurements would have to be taken on a sample of loads and would have to provide for the variations in scaling practice common to the region. With such data it would be possible to make valid price comparisons among log rules, as well as with such other measures as standard cords, pulpwood units, or tons.

9. Minnesota's aspen supply--present and future

Aspen comprises nearly 5.5 million of Minnesota's 18.5 million acres of commercial forest land and accounts for almost one-third of the State's timber volume. A series of projections of aspen timber volumes indicate

that a substantial increase in the volume of aspen timber is in prospect. This suggests that Minnesota's aspen resources can support a much larger industry in the decades immediately ahead.

10. Log exports continue to rise in Pacific Northwest

A quarterly report on production, prices, employment, and trade in the Pacific Northwest timber industries indicated that log exports continued to rise sharply in 1966. The increase in exports added in an important way to the competition for stumpage and logs in Western Washington and Western Oregon and contributed to the difficulties of the domestic timber using industries, especially the small nonintegrated mills that depend largely on public timber.

11. The market for wood pallets in the steel industry

A survey of pallet use showed that in 1964 about 80 million feet of lumber was used in the manufacture of wooden pallets and skids for the steel industry. The survey also showed that the steel industry market is specialized, one in which most pallets are essentially custom items produced by manufacturers supplying only the purchasing mill. The market for pallets in the steel industry is expected to increase by nearly 25 percent by 1970 due to expansion of the industry and increased use of pallets and skids.

12. Pulpwood chip production and markets in the Lake States

Analysis of pulpwood chip production and marketing in the Lake States in 1965 showed that 35 sawmills were producing chips for sale to pulpmills. In addition, there were six other active chippers not associated with a sawmill. While markets for most of these chips were within 100 miles of their origin, some chips were being shipped as far as 300 miles. Most chips were sold on a weight basis.

13. Costs and returns for hardwood lumber production

Profit margins at hardwood sawmills, especially the smaller mills, have shrunk steadily in recent years. It has been difficult to institute cost control programs because most operators have little idea what it costs to perform the different operations or what segments entail the largest expense. A detailed study of seven circular mills in Ohio and Kentucky showed that the larger mills performing more seasoning and secondary manufacture and selling a wider array of products had larger operating margins. The items of greatest fixed cost were depreciation and insurance; among variable costs the largest items were cost of stumpage and logs, purchase of lumber for resale, labor and office expense, cost of distributing products, and administration. To the extent that the mills studied are representative of most mills in the region, the findings point out those operating and

management factors on which cost control efforts should be concentrated in a campaign to increase operating efficiency and profits of Appalachian mills.

14. Determining weight-volume relationships for saw logs

Weight-scaling has come into widespread use in the South as a result of research on this new method of measuring and marketing timber products. Geometric relationships between log weight and scale volumes shown by the Doyle, Scribner, and International log rules have been established to provide a general model for weight-scaling equations. In this model provision has been made for determining the effects of such factors as log size and position in the tree, bark thickness, trim allowance, and wood density. The model provides accurate and consistent estimates of scale for either individual logs or truckloads.

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WORK AND LINE PROJECTS, TIMBER MANAGEMENT RESEARCH DIVISION

FOREST SERVICE, U.S.D.A.

May 1, 1966 to April 30, 1967

Work and line project number		Work and line project titles	Work locations	Line projects summary index
CPO	FS			
		SILVICULTURE OF EASTERN FOREST TYPES		
FS 1 1-1 (NC)	FS-NC-1101	Site requirements of northern conifers and hardwoods	St. Paul, Minnesota	
FS 1 1-2 (NC)	FS-NC-1102	Silviculture of northern hardwoods in the Lake States	Marquette, Michigan	I, A-1, A-5
FS 1 1-3 (NC)R	FS-NC-1103 (Rev.)	Silviculture of northern conifers and aspen	Grand Rapids, Minn.	I, B-3
FS 1 1-4 (NC)R	FS-NC-1104 (Rev.)	Silviculture of mixed hardwoods	East Lansing, Mich.	
FS 1 1-5 (NC)R	FS-NC-1105 (Rev.)	Plantation management of Lake States conifers	East Lansing, Mich.	
FS 1 1-6 (NC)	FS-NC-1106	Seedling physiology and establishment of central hardwoods	Ames, Iowa	I, A-1, A-7
FS 1 1-46 (NC)	FS-NC-1107	Soil and site requirements for walnut	Carbondale, Illinois	
FS 1 1-10 (NC)	FS-NC-1108	Culture of black walnut	Carbondale, Illinois	I, A-4
FS 1 1-11 (NC)R	FS-NC-1109 (Rev.)	Silviculture of oak-hickory forests	Columbia, Missouri	I, B-1
FS 1 1-12 (NE)	FS-NE-1101	Silviculture of spruce and fir	Orono, Maine	
FS 1 1-14 (NE)	FS-NE-1103	Silviculture of northern Appalachian hardwoods	Parsons, W. Virginia	I, A-5, B-3
FS 1 1-15 (NE)	FS-NE-1104	Silviculture of northern hardwoods in the Northeast	Durham, N. Hampshire	I, A-3, B-1, B-2
FS 1 1-19 (NE)	FS-NE-1108	Silviculture of black cherry and red maple	Warren, Pa.	I, A-5
FS 1 1-9 (NE)	FS-NE-1109	Silviculture of mountain hardwoods	Berea, Kentucky	I, A-3
FS 1 1-20 (SE)R	FS-SE-1101 (Rev.)	Silviculture of Virginia and shortleaf pine	Blacksburg, Virginia	
FS 1 1-21 (SE)R	FS-SE-1102 (Rev.)	Silviculture of southern Appalachian hardwoods	Asheville, N. C.	I, A-3, B-1
FS 1 1-22 (SE)R	FS-SE-1103 (Rev.)	Interrelationships of soils and trees in the piedmont	Res. Triangle, N. C.	I, A-1
FS 1 1-25 (SE)R	FS-SE-1106 (Rev.)	Silviculture of Coastal Plain timber types	Charleston, S.C.	
FS 1 1-26 (SE)R	FS-SE-1107 (Rev.)	Silviculture of southern Piedmont hardwoods	Athens, Georgia	I, A-3, A-7
FS 1 1-27 (SE)R	FS-SE-1108 (Rev.)	Silviculture of Piedmont loblolly pine, including plantation management	Macon, Georgia	I, A-2
FS 1 1-29 (SE)R	FS-SE-1110 (Rev.)	Silviculture of slash pine type	Olustee, Florida	I, A-2, A-3
FS 1 1-34 (SE)	FS-SE-1111	Pine establishment in sandhills	Marianna, Florida	I, A-1
FS 1 1-33 (SO)	FS-SO-1101	Silviculture of the Ozark pine type	Harrison, Arkansas	I, A-1, B-2
FS 1 1-30 (SO)	FS-SO-1102	Artificial regeneration of southern pines	Alexandria, Louisiana	I, A-2, C-2
FS 1 1-36 (SO)	FS-SO-1105	Artificial regeneration of Cumberland Plateau hardwoods	Sewannee, Tennessee	I, B-3
FS 1 1-31 (SO)	FS-SO-1106	Silviculture of southern hardwoods	Stoneville, Mississippi	I, A-2, A-3, A-7
FS 1 1-32 (SO)	FS-SO-1107	Silviculture of loblolly pine in the mid-South	Crossett, Arkansas	I, A-1, A-2, A-7
FS 1 1-43 (SO)	FS-SO-1108	Technology of eastern forest tree seed	State College, Miss.	I, A-3
FS 1 1-47 (SO)	FS-SO-1109	Silvicultural aspects of combining timber and game	Nacogdoches, Texas	
FS 1 1-49 (SO)	FS-SO-1110	Longleaf pine silviculture	Auburn, Alabama	I, A-2, B-3
FS 1 1-37 (ITF)	FS-ITF-1101	Silviculture of tropical trees	Rio Piedras, P.R.	I, C-2
FS 1 1-39 (ITF)	FS-ITF-1102	Applied tropical forestry	Rio Piedras, P. R.	

WORK AND LINE PROJECTS, TIMBER MANAGEMENT RESEARCH DIVISION

FOREST SERVICE, U. S. D. A.

Work and line project number		Work and line project titles	Work locations	Line projects summary index
CPO	FS			
		SILVICULTURE OF EASTERN FOREST TYPES		
FS P-2	FS P-2	Pioneering research on physiology of wood formation	Rhinelander, Wis.	I, A-7
FS P-6	FS P-6	Pioneering research on forest soils	Res. Triangle, N. C.	
FS 1 1-38 (WO)	FS-WO-1101	Physiology of tree growth, nutrition, and mycorrhizal relationships	Beltsville, Maryland	
FS 1 1-40 (WO-Gr.)	FS-WO-1102 (Gr.)	Uptake, translocation, and cycling of residual pesticides by woody plants	Athens, Georgia	
FS 1 1-42 (WO-Gr.)	FS-WO-1104 (Gr.)	Biosynthesis of cellulose in trees	Gainesville, Florida	
FS 1 1-45 (WO-Gr.)	FS-WO-1106 (Gr.)	Biochemistry of tree seed dormancy	Syracuse, New York	
		SILVICULTURE OF WESTERN FOREST TYPES		
FS 1 2-3 (PNW)	FS-PNW-1201	Seeding, planting, and nursery practices in the Pacific Northwest	Portland, Oregon	I, A-2
FS 1 2-5 (PNW)	FS-PNW-1203	Silviculture of lodgepole and ponderosa pine and interior-mixed conifers	Bend, Oregon	I, A-3, B-1
FS 1 2-6 (PNW)	FS-PNW-1204	Silviculture of true fir-mountain hemlock and Sitka spruce-western hemlock types	Corvallis, Oregon	I, A-1, A-3, A-4
FS 1 2-7 (PNW)	FS-PNW-1205	Silviculture of mixed pines and Douglas-fir	Roseburg, Oregon	I, A-7
FS 1 2-8 (PNW)	FS-PNW-1206	Brushfield reclamation	Corvallis, Oregon	
FS 1 2-9 (PNW)	FS-PNW-1207	Silviculture of young-growth Douglas-fir and related species	Olympia, Washington	I, A-5
FS 1 2-10 (PNW)	FS-PNW-1208	Prevention and control of animal damage to forest trees	Olympia, Washington	I, A-6
FS 1 2-1 (PNW)	FS-PNW-1210	Silviculture of coastal forests in Alaska	Juneau, Alaska	I, A-3
FS 1 2-2 (PNW)	FS-PNW-1211	Silviculture of interior Alaska forests	College, Alaska	I, A-3, A-4, A-6
FS 1 2-12 (PSW) R	FS-PSW-1201 (Rev.)	Silviculture of Sierra Nevada conifer types	Redding, California	I, A-2, A-6, B-2
FS 1 2-14 (PSW) R	FS-PSW-1203 (Rev.)	Silviculture of redwood and Douglas-fir	Arcata, California	
FS 1 2-16 (PSW) R	FS-PSW-1205 (Rev.)	Timber and watershed research in Hawaii	Honolulu, Hawaii	I, A-2
FS 1 2-17 (INT)	FS-INT-1201	Silviculture of western white pine	Moscow, Idaho	I, A-2, C-1
FS 1 2-18 (INT)	FS-INT-1202	Silviculture of ponderosa pine and interior Douglas-fir	Boise, Idaho	
FS 1 2-19 (INT)	FS-INT-1203	Silviculture of lodgepole pine in the northern and intermountain regions	Bozeman, Montana	I, A-2
FS 1 2-20 (INT)	FS-INT-1204	Silviculture of western larch and Engelmann spruce	Missoula, Montana	

WORK AND LINE PROJECTS, TIMBER MANAGEMENT RESEARCH DIVISION
FOREST SERVICE, U. S. D. A.

Work and line project number		Work and line project titles	Work locations	Line projects summary index
CPO	FS			
		SILVICULTURE OF WESTERN FOREST TYPES		
FS 1 2-27 (INT)	FS-INT-1205	Forest ecosystem management and protection in Northern Rocky Mountain and Intermountain regions	Ogden, Utah	
FS 1 2-21 (RM)	FS-RM-1201	Silviculture of spruce-fir and lodgepole pine in the central Rocky Mountains	Ft. Collins, Colorado	I, A-3
FS 1 2-22 (RM)	FS-RM-1202	Silviculture of mixed conifers and aspen	Ft. Collins, Colorado	I, A-3, B-1
FS 1 2-23 (RM)	FS-RM-1203	Silviculture of ponderosa pine in the Southwest	Flagstaff, Arizona	
FS 1 2-25 (RM)	FS-RM-1205	Silviculture of Black Hills ponderosa pine	Rapid City, S. Dakota	
FS 1 1-41 (WO-Gr.)	FS-WO-1103 (Gr.)	The basis for the palatability of ruminant forage plants	Davis, California	
FS 1 1-44 (WO-Gr.)	FS-WO-1105 (Gr.)	An ecological study of forest vegetation in western Wyoming	Pullman, Washington	
		TIMBER MEASUREMENT		
FS 1 3-1 (PNW)R	FS-PNW-1301 (Rev.)	Measurement and related timber management techniques in the Northwest	Portland, Oregon	I, B-1
FS 1 3-6 (PSW)R	FS-PSW-1301 (Rev.)	Measurement and analysis techniques for management planning	Berkeley, California	I, B-1, B-3
FS 1 3-2 (INT)	FS-INT-1301	Measurement studies of forest timber types and species in the northern Rocky Mountain and Intermountain regions	Moscow, Idaho	I, B-1
FS 1 3-5 (RM)	FS-RM-1301	Timber measurement and management planning procedures for timber types and species in the Rocky Mountains and southwestern region	Ft. Collins, Colorado	I, B-1
FS 1 3-8 (NE)	FS-NE-1302	Timber measurement and management planning procedures for eastern hardwoods	Columbus, Ohio	
FS 1 3-9 (SE) R	FS-SE-1301 (Rev.)	Measurement studies of forests of the Southeast	Res. Triangle, N. C.	
FS P-1	FS P-1	Pioneering research in forest measurements	Berkeley, California	I, B-2

WORK AND LINE PROJECTS, TIMBER MANAGEMENT RESEARCH DIVISION
FOREST SERVICE, U. S. D. A.

Work and line project number		Work and line project titles	Work locations	Line project summary index
CPO	FS			
		FOREST GENETICS		
FS 1 4-8 (PNW)	FS-PNW-1401	Genetics of northwestern trees	Corvallis, Oregon	I, C-3
FS 1 4-1 (PSW)	FS-PSW-1401	Genetics of western conifers	Berkeley, California	I, A-2, A-7, C-2
FS 1 4-11 (NC)	FS-NC-1401	Genetics of northern forest trees	Rhinelander, Wis.	I, A-7, C-1
FS 1 4-9 (NC)	FS-NC-1402	Tree improvement of black walnut	Carbondale, Illinois	
FS 1 4-3 (NE)R	FS-NE-1401 (Rev.)	Tree improvement of northeastern conifers and hardwoods	Durham, N.H.	
FS 1 4-13 (SE)	FS-SE-1401	Southern pine tree improvement	Macon, Georgia	I, A-2, C-1, C-3
FS 1 4-4 (SO)	FS-SO-1401	Genetics of southern pines and hardwoods	Gulfport, Miss.	I, C-1, C-3
FS 1 4-5 (WO)	FS-WO-1401	Identification, classification, and distribution of forest trees	Washington, D.C.	I, A-7
FS 1 4-7 (WO-Gr.)	FS-WO-1402 (Gr.)	Breeding pines for resistance to Neodiprion sawflies	New Haven, Conn.	
FS 1 4-6 (WO-Gr.)	FS-WO-1403 (Gr.)	Resistance of pines to the white pine weevil	University Park, Pa.	I, C-1
FS 1 4-10 (WO-Gr.)	FS-WO-1404 (Gr.)	Physiology and biochemistry of root initiation in black walnut	New Brunswick, N. J.	
FS 1 4-12 (WO-Gr.)	FS-WO-1405 (Gr.)	Ecotypic variation in sweetgum	Austin, Texas	
		TIMBER-RELATED CROPS		
FS 1 5-10(RM)	FS-RM-1501	Shelterbelts research in southern and central Great Plains	Lincoln, Nebraska	I, A-2. D-3, D-4
FS 1 5-8 (RM)	FS-RM-1502	Shelterbelts research in northern Great Plains	Bottineau, N. Dakota	
FS 1 5-1 (NE)R	FS-NE-1501 (Rev.)	Maple sap production and related tree improvement	Burlington, Vermont	I, D-2
FS 1 5-4 (NE)	FS-NE-1502	Christmas trees and other decorative or medicinal plants	Berea, Kentucky	I, D-4
	FS-NE-1503	Improving the human environment with trees	Upper Darby, Pa.	I, A-1
FS 1 5-2 (SE) R	FS-SE-1501 (Rev.)	Naval stores gum production and physiology	Olustee, Florida	
FS 1 5-7 (SE)	FS-SE-1502	Naval stores tree improvement	Olustee, Florida	I, C-1, D-1
FS 1 5-3 (WO-Gr.)	FS-WO-1501 (Gr.)	Factors influencing carbohydrate metabolism of sugar maple	Burlington, Vermont	
FS 1 5-6 (WO-Gr.)	FS-WO-1502 (Gr.)	The chemistry of resin acids from oleoresin	Athens, Georgia	

WORK AND LINE PROJECTS, TIMBER MANAGEMENT RESEARCH DIVISION
FOREST SERVICE, U. S. D. A.

Work and line project number		Work and line project titles	Work locations	Line project summary index
CPO	FS			
		PL 480 PROJECTS		
S3-FS-6		Mineral nutrition of Pinus elliottii	Sao Paulo, Brazil	
S4-FS-3		Investigation in rooting and growth induction of short shoots of Pinus radiata	Santiago, Chile	
S4-FS-6		Biosynthesis of terpenes in Pinus radiata	Santiago, Chile	I, D-1
S4-FS-7		Effect of growth substances in pine meristems	Santiago, Chile	
S5-FS-4		Basic studies of the physiological changes in the transition from juvenile to mature stage in certain forest trees	Bogota, Colombia	
S5-FS-5		Studies on the production of homozygons lines of pines	Bogota, Colombia	
S5-FS-6		Genetic and environmental influences on growth habits of southern U. S. pines	Medellin, Colombia	
E8-FS-45		Population study concerning spruce with special reference to the variation in the characteristics of wood	Helsinki, Finland	
E8-FS-46		The value of alder in adding nitrogen in forest soils	Helsinki, Finland	I, A-1
E8-FS-47		Induced polyploidy and other mutations in birch, Betula spp.	Turku, Finland	
E8-FS-48		DNA and RNA studies on Scotch pine with special attention to finding a method to increase flowering	Turku, Finland	
E8-FS-49		The role of soil fungi in the formation of different humus types	Helsinki, Finland	
E8-FS-50		Pollen dispersal and its significance in silviculture and genetics	Helsinki, Finland	
E8-FS-51		Effect of silvicultural practices upon the arthropod, annelid, and nematode populations in forest litter and soil	Helsinki, Finland	I, A-1
E8-FS-64		The use of serological technique in detecting incompatibility barriers in the pines	Helsinki, Finland	
E11-FS-1		Reconnaissance breeding in certain hard pines of the Mediterranean area	Thessaloniki, Greece	
E11-FS-2		Nutritional studies of forest trees under various soil and nutrient solution conditions	Athens, Greece	
E11-FS-5		Genetic relationships among pines of the Mediterranean	Thessaloniki, Greece	
A7-FS-10		Investigations on mycorrhizae-forming fungi with special reference to conifers in India	Dehra Dun, India	
A7-FS-11		Investigations on the use of auxins in vegetative reproduction of forest plants	Chandigarh, India	

WORK AND LINE PROJECTS, TIMBER MANAGEMENT RESEARCH DIVISION
FOREST SERVICE, U.S.D.A.

Work and line project number		Work and line project titles	Work locations	Line project summary index
CPO	FS			
		PL 480 PROJECTS		
A7-FS-12		Cytology of some Himalayan hardwoods and cytological and morphological differences or similarities in ecotypes or clines of Himalayan forest trees	Chandigarh, India	
A7-FS-15		Cooperative tree improvement research on teak	Dehra Dun, India	
A7-FS-35		Techniques for inducing mutations and polyploidy in some species of importance in forestry	Dehra Dun, India	
A7-FS-36		Tissue and cell culture of pines and allied conifers	Delhi, India	
A7-FS-53		Investigations into the Abies and Juniperus complexes in the Himalayas	Chandigarh, India	
A10-FS-5		Factors controlling the annual rhythm of wood production	Jerusalem, Israel	
A10-FS-7		Mechanisms of drought tolerance and drought avoidance in conifers of the Mediterranean zone and the arid West of the United States	Rehovot, Israel	
A10-FS-8		The development of techniques for the vegetative propagation of pine trees by means of needle fascicles	Jerusalem, Israel	
A10-FS-10		Effect of transpiration retardants on certain physiological processes of forest seedlings and other plants	Jerusalem, Israel	
A10-FS-15		Morphological and anatomical changes related to resin stimulation	Jerusalem, Israel	
E15-FS-3		Factors affecting the difficult rooting of cuttings in some poplars (i.e. Populus deltoides v. angulata, P. alba, P. tremula) and their hybrids	Rome, Italy	
E15-FS-6		The problem of incompatibility in grafting of forest trees, especially pines	Florence, Italy	
E15-FS-8		Comparative studies of the photosynthetic efficiencies of poplar hybrids	Milan, Italy	
A13-FS-1		The fundamental mechanism of root-primordia formation of cuttings	Suwon, Korea	
E21-FS-17		Investigations of pure culture of mycorrhizal fungi of pine (Pinus sylvestris L.)	Warsaw, Poland	
E21-FS-20		Population study of spruce in Poland	Warsaw, Poland	
E21-FS-22		Influence of sowing of lupine on tree growth	Warsaw, Poland	
E21-FS-23		Decomposition of forest litter and thick moss layers in spruce and pine stands	Warsaw, Poland	

WORK AND LINE PROJECTS, TIMBER MANAGEMENT RESEARCH DIVISION
FOREST SERVICE, U.S.D.A.

Work and line project number		Work and line project titles	Work locations	Line project summary index
CPO	FS			
		PL 480 PROJECTS		
E21-FS-24		Studies in wood formation with emphasis on seasonal changes	Warsaw, Poland	
E21-FS-26		A survey of endogenous growth substances in certain forest trees	Torun, Poland	
E21-FS-31		Studies on the variability of photosynthesis of pine trees during development under different conditions of growth	Warsaw, Poland	
E21-FS-32		Effect of gibberellin on auxin metabolism and its relation to growth of Scots pine seedlings (Pinus sylvestris)	Poznan, Poland	
E21-FS-33		Variation between Picea abies provenances in their ability to utilize mineral nutrients under competitive conditions	Poznan, Poland	
E21-FS-40		The orientation of the plane of cell division in cambia of trees and factors controlling it	Wroclaw, Poland	
E25-FS-14		Ontogenesis of enzymes induced in pine seed through cold stratification	Madrid, Spain	I, A-7
E25-FS-15		Minor elements distribution in cellular fluids of floral and foliar tissue of trees	Madrid, Spain	
E25-FS-16		Isolation and identification of plant hormones associated with callus and root formation	Santiago, Spain	
E25-FS-20		The determination of levels of boron, manganese, and molybdenum sufficient for growth of Monterey pine (Pinus radiata)	Madrid, Spain	I, A-7
E25-FS-23		Spanish contribution to multilingual forest terminology with Hispano-American terms	Madrid, Spain	
E25-FS-24		Biosynthesis of terpenes in pine	Granada, Spain	
E25-FS-25		The determination of levels of Fe, Cu, and Zn sufficient for the growth of Monterey pine	Madrid, Spain	
A6-FS-2		The genus Abies	Taipei, Taiwan	
E30-FS-4		Developing improved poplars	Novi Sad, Yugoslavia	
E30-FS-6		Develop breeding techniques for oak	Belgrade, Yugoslavia	
E30-FS-7		Breed walnuts for high quality wood products	Belgrade, Yugoslavia	

Line Project Check List -- Reporting Year May 1, 1966 to April 30, 1967
WATERSHED, RECREATION AND RANGE RESEARCH DIVISION
FOREST SERVICE, U.S.D.A.

Work and Line Project Number		Work and Line Project Titles	Work Locations During Past Year	Line Project Inc. in Summary of Progress (Yes-No)	Line Project Inc. in Summary of Area and Subheading
CPO	FS				
		FOREST SOIL AND WATER RESEARCH			
FS 1 6-2 (PNW)	FS-PNW-1601	Water yield and erosion - Columbia River	Wenatchee, Washington	Yes	II,A-1-b
FS 1 6-3 (PNW)	FS-PNW-1602	Watershed logging methods and streamflow - western Cascades	Corvallis, Oregon	"	II,A-2-a,A-4
FS 1 6-39 (PNW)	FS-PNW-1603	Pesticides - soil and water	Corvallis, Oregon	"	II,A-2-a,A-4
FS 1 6-1 (PNW)	FS-PNW-1604	Erosion and sedimentation, coastal forests	Juneau, Alaska	No	
FS 1 6-4 (PSW)(R)	FS-PSW-1601(Rev.)	Water yield improvement, conifer zone	Berkeley, California	Yes	II,A-1-b
FS 1 6-5 (PSW)(R)	FS-PSW-1602(Rev.)	Hydrologic analysis methods	Berkeley, California	"	II,A-2-a,1-C
FS 1 6-6 (PSW)(R)	FS-PSW-1603(Rev.)	Flood and sediment reduction, conifer zone	Berkeley, California	"	II,A-2-a
FS 1 6-7 (PSW)(R)	FS-PSW-1604(Rev.)	Brushland flood and sediment reduction - Southwest	Glendora, California	"	II,A-3-d
FS 1 6-8 (PSW)(R)	FS-PSW-1605(Rev.)	Brushland water yield improvement - Southwest	Glendora, California	No	
FS 1 6-10 (INT)(R)	FS-INT-1601(Rev.)	Streamflow regulation in Northern Rocky Mountain forests	Moscow, Idaho	Yes	II,A-2-a
FS 1 6-11 (INT)	FS-INT-1602	Soil stabilization, logging - Northern Rocky Mountains	Boise, Idaho	"	II,A-2-b
FS 1 6-12 (INT)(R)	FS-INT-1603(Rev.)	Watershed rehabilitation and protection - high rangelands	Logan, Utah	"	II,A-3-b,2-b, 3-d
FS 1 6-14 (INT)(R)	FS-INT-1605(Rev.)	Water yield improvement - Great Basin	Logan, Utah	No	
FS 1 6-16 (RM)	FS-RM-1601	Alpine snow and avalanche research	Fort Collins, Colorado	Yes	II,A-1-a
FS 1 6-17 (RM)	FS-RM-1602	Water yield - snowpack timber - Rocky Mountains	Fort Collins, Colorado	"	II,A-2-a
FS 1 6-18 (RM)(R)	FS-RM-1603(Rev.)	Water yield, soil stabilization - Big Horn, North Platte	Laramie, Wyoming	No	
FS 1 6-19 (RM)	FS-RM-1604	Watershed rehabilitation - Southwest	Albuquerque, New Mexico	Yes	II,A-3-b
FS 1 6-21 (RM)(R)	FS-RM-1606(Rev.)	Water yield improvement - Southwest	Tempe, Arizona	"	II,A-1-c
FS 1 6-46 (RM)	FS-RM-1607	Radiant energy and water yield - Rocky Mountains	Fort Collins, Colorado	"	II,A-1-b,1-c
FS 1 6-38 (RM)	FS-RM-1608	Water yield improvement, stabilization - Black Hills	Rapid City, S. Dak.	"	II,A-1-b,3-b
FS 1 6-43 (NC)	FS-NC-1601	Runoff reduction and streamflow improvement - nonglaciated	La Crosse, Wisconsin	"	II,A-2-a
FS 1 6-44 (NC)	FS-NC-1602	Bog and swamp hydrology - northern forests	Grand Rapids, Minn.	"	II,A-4,1-c
FS 1 6-42 (NC)	FS-NC-1603	Ground water hydrology and streambank erosion	Cadillac, Michigan	"	II,A-3-a
FS 1 6-27 (NE)(R)	FS-NE-1601(Rev.)	Water yield improvement - New England	Durham, New Hampshire	"	II,A-1-b
FS 1 6-28 (NE)(R)	FS-NE-1602(Rev.)	Floods and water yield - central Appalachians	Parsons, West Virginia	"	II,A-1-c,2-a
FS 1 6-29 (NE)(R)	FS-NE-1603(Rev.)	Watershed correlation and synthesis	Upper Darby, Penna.	"	II,A-1-c,2-a
FS 1 6-30 (NE)(R)	FS-NE-1604(Rev.)	Stream regimen and water yields - Northeast	Syracuse, New York	"	II,A-1-b
FS 1 6-25 (NE)(R)	FS-NE-1605(Rev.)	Strip-mined area restoration	Berea, Kentucky	"	II,A-3-c
FS 1 6-26 (NE)	FS-NE-1606	Management of storm runoff	Columbus, Ohio	"	II,A-2-a
FS 1 6-31 (SE)(R)	FS-SE-1601(Rev.)	Water yield improvement, mountains - Piedmont	Franklin, N. C.	"	II,A-1-c
FS 1 6-32 (SE)(R)	FS-SE-1602(Rev.)	Wetland forest soil improvement	Charleston, S. C.	"	II,A-4
FS 1 6-34 (SO)	FS-SO-1601	Water timing - Ozark-Ouachita	Harrison, Arkansas	"	II,A-1-c

Line Project Check List -- Reporting Year May 1, 1966 to April 30, 1967
WATERSHED, RECREATION AND RANGE RESEARCH DIVISION
FOREST SERVICE, U.S.D.A.

Work and Line Project Number		Work and Line Project Titles	Work Locations During Past Year	Line Project Inc. in Summary of Progress (Yes-No)	Line Project Inc. in Area and Subheading
CPO	FS				
		FOREST SOIL AND WATER RESEARCH			
FS 1 6-35 (SO)	FS-SO-1602	Coastal plain hydrology - South	Oxford, Mississippi	Yes	II, A-3-a
FS 1 6-36 (SO)	FS-SO-1603	Watershed rehabilitation - Coastal Plain	Oxford, Mississippi	"	II, A-3-a
FS 1 6-37 (SO)	FS-SO-1604	Management of erosive watersheds	Oxford, Mississippi	"	II, A-3-a
FS 1 6-40 (WO)(Gr)	FS-WO-1601(Gr)	Soil wetability and treatment in relation to water movement	Riverside, California	No	
FS 1 6-41 (WO)(Gr)	FS-WO-1602(Gr)	The insecticide "Sevin" as a watershed pollutant	Syracuse, New York	No	
FS 1 6-45 (WO)(Gr)	FS-WO-1603(Gr)	Fate of DDT and Zectran in forest soils	Seattle, Washington	Yes	II, A-2-a
		P. L. 480 PROJECTS			
	A10-FS-13	Study of difference in effects of forest and other vegetative covers on water yield	Israel	"	II, A-5-b
	E21-FS-36	Seasonal variability of soil moisture and levels of groundwater table on lowland areas, as they affect water use, growth and development of pine stands	Poland	"	II, A-5-c

Line Project Check List -- Reporting Year May 1, 1966 to April 30, 1967
WATERSHED, RECREATION AND RANGE RESEARCH DIVISION
FOREST SERVICE, U.S.D.A.

Work and Line Project Number		Work and Line Project Titles	Work Locations During Past Year	Line Project Inc. in Summary of: Progress (Yes-No)	Area and Subheading
CPO	FS				
		FOREST RECREATION RESEARCH			
FS 1 9-1 (PSW)(R)	FS-PSW-1901(Rev.)	Recreation management guides - California	Berkeley, California	Yes	II,B-2,3
FS 1 9-2 (NC)	FS-NC-1901	Recreation - North Central	St. Paul, Minnesota	"	II,B-2
FS 1 9-3 (NC)	FS-NC-1902	North Central - University of Michigan Cooperative Recreation Research Unit	Ann Arbor, Michigan	No	
FS 1 9-4 (NE)	FS-NE-1903	Small woodland recreation	Syracuse, New York	Yes	II,B-1
FS 1 9-5 (NE)(R)	FS-NE-1901(Rev.)	Forest recreation market analyses - Northeastern	Syracuse, New York	"	II,B-1
FS 1 9-6 (NE)	FS-NE-1902	Syracuse recreation project	Syracuse, New York	No	
FS 1 9-8 (INT)	FS-INT-1901	Recreation management and planning - Intermountain	Ogden, Utah	Yes	II,B-1
FS 1 9-9 (INT)	FS-INT-1902	Forest recreation research unit in cooperation with Utah State University	Logan, Utah	"	II,B-2
FS 1 9-11 (PNW)	FS-PNW-1901	Wilderness recreation dynamics	Portland, Oregon	No	
FS 1 9-13 (SE)	FS-SE-1901	Forest Recreation management research	Asheville, N. C.	Yes	II,B-2
	FS-SE-1902	Cooperative forest recreation unit	Raleigh, N. C.	"	II,B-1
FS 1 9-15 (RM)	FS-RM-1901	Forest recreation research - Rocky Mountains	Fort Collins, Colorado	"	II,B-1
FS 1 9-16 (WO)(Gr)	FS-WO-1902(Gr)	Some effects of landscape enhancement on timber production	Cambridge, Mass.	No	
FS 1 9-17 (WO)(Gr)	FS-WO-1903(Gr)	Measurement of the esthetic appeal of managed forest and wild land roadside environments	Gainesville, Florida	"	

Line Project Check List -- Reporting Year May 1, 1966 to April 30, 1967
WATERSHED, RECREATION, AND RANGE RESEARCH DIVISION
FOREST SERVICE, U.S.D.A.

Work and Line Project Number		Work and Line Project Titles	Work Locations During Past Year	Line Project Inc. in Summary of: Progress (Yes-No)	Line Project Inc. in Summary of: Area and Subheading
CPO	FS				
		RANGE MANAGEMENT RESEARCH			
FS 1 7-1 (PNW)	FS-PNW-1701	Range ecology and management -- Northwest	La Grande, Oregon	Yes	II, C-1-b, 2-a, 3-a, 5
FS 1 7-3 (PSW)(R)	FS-PSW-1701 (Rev.)	Management of perennial grass ranges	Berkeley, California	"	II, C-1-a, 3-a
FS 1 7-4 (PSW)(R)	FS-PSW-1702 (Rev.)	Management of annual plant and related ranges	Fresno, California	"	II, C-1-a, 3-b, 4
FS 1 7-7 (INT)	FS-INT-1701	Sagebrush, cheatgrass, and granitic soil ranges	Boise, Idaho	"	II, C-3-a
FS 1 7-8 (INT)	FS-INT-1702	Northern Rocky Mountain grasslands	Bozeman, Montana	"	II, C-1-a, 5
FS 1 7-9 (INT)	FS-INT-1703	Salt-desert shrub, sagebrush grass, and pinyon-juniper ranges	Provo, Utah	"	II, C-1-a, 2-a, 5
FS 1 7-10(INT)	FS-INT-1704	Management of mountain herbland, brushland, and aspen ranges	Logan, Utah	"	II, C-1-a, 4
FS 1 7-11 (RM)	FS-RM-1701	Mountain ranges - central Rockies	Fort Collins, Colorado	"	II, C-2-a, 2-b, 2-c, 3-a, 3-b, 4
FS 1 7-12 (RM)	FS-RM-1702	Range biometry	Fort Collins, Colorado	"	II, C-2-b
FS 1 7-13 (RM)	FS-RM-1703	Alpine and subalpine ranges	Laramie, Wyoming	"	II, C-3-a, 4
FS 1 7-14 (RM)	FS-RM-1704	Southwestern seeded ranges	Albuquerque, N.M.	"	II, C-1-a, 3-b
FS 1 7-15 (RM)	FS-RM-1705	Southwestern chaparral, woodland, and forest ranges	Flagstaff, Arizona	"	II, C-1-a, 3-a, 4
FS 1 7-16 (RM)	FS-RM-1706	Semidesert cattle ranges	Tucson, Arizona	"	II, C-1-a, 2-b, 3-a, 4
FS 1 7-21 (RM)	FS-RM-1707	Range inventory and evaluation	Fort Collins, Colorado	"	II, C-1-a
FS 1 7-17 (NC)	FS-NC-1701	Range evaluation and management	Columbia, Missouri	"	II, C-2-a, 2-c, 3-a, 4
FS 1 7-18 (SE)(R)	FS-SE-1701 (Rev.)	Multiresources management of the pine-wiregrass type	Fort Myers, Florida	"	II, C-4
FS 1 7-19 (SO)	FS-SO-1701	Southern pine cattle ranges	Alexandria, Louisiana	"	II, C-1-b, 2-b, 3-a, 4
FS 1 7-20 (WO)	FS-WO-1701	Range plant taxonomy	Washington, D.C.	"	II, C-1-b
		P.L. 480 Projects			
	A10-FS-6	Germination of seeds of desert plants	Jerusalem, Israel	"	II, C-1-a
	E25-FS-1	Studies of botany, ecology, biology, and pascicology of the principal existing species in the spontaneous pastur-grounds of the mountains of our semiarid regions	Madrid, Spain	"	II, C-1-b

Line Project Check List -- Reporting Year May 1, 1966 to April 30, 1967
WATERSHED, RECREATION, AND RANGE RESEARCH DIVISION
FOREST SERVICE, U.S.D.A.

Work and Line Project Number		Work and Line Project Titles	Work Locations During Past Year	Line Project Inc. in Summary of Progress (Yes-No)	Area and Subheading
CPO	FS				
		WILDLIFE HABITAT RESEARCH			
FS 1 8-1 (PNW)	FS-PNW-1801	Big-game habitat - Pacific Northwest	La Grande, Oregon	Yes	II,D-1,2,3-b
FS 1 8-3 (PSW)(R)	FS-PSW-1801(Rev.)	Wildlife habitat research - California	Berkeley,California	"	II,D-1,3-a,3-b
FS 1 8-4 (INT)	FS-INT-1801	Deer winter range - Idaho	Boise, Idaho	"	II,D-1
FS 1 8-5 (INT)	FS-INT-1802	Northern Rockies forest wildlife habitat	Missoula,Montana	"	II,D-1,2,3-c
FS 1 8-6 (INT)	FS-INT-1803	Game range restoration and wildlife-livestock relations	Provo, Utah	"	II,D-1,3-b
FS 1 8-7 (RM)	FS-RM-1801	Forest game and fish habitat-Central Rockies	Fort Collins,Colorado	"	II,D-1,2,3-a
FS 1 8-8 (RM)	FS-RM-1802	Wildlife habitat--southwestern vegetation types	Tempe, Arizona	"	II,D-2,3-a,3-c
FS 1 8-9 (RM)	FS-RM-1803	Wildlife habitat - Black Hills	Rapid City, S. Dak.	"	II,D-1,3-a,3-b
FS 1 8-10(RM)	FS-RM-1804	Management of elk ranges in the central Rocky Mountains	Laramie, Wyoming	No	New Project
FS 1 8-11(NC) (R)	FS-NC-1801 (Rev.)	Environment and treatment of wildlife habitat-Lake States	Rhinelander,Wisconsin	"	II, D, 3-a
FS 1 8-13(NE) (R)	FS-NE-1801 (Rev.)	Ecological aspects of wildlife-timber production	Warren, Pa.	"	II, D-2,3-a
FS 1 8-14(NE)	FS-NE-1802	Turkey,squirrel,and other deer habitat-Appalachian forests	Morgantown, W.Va.	"	New Project
FS 1 8-15(SE) (R)	FS-SE-1801 (Rev.)	Forest wildlife habitat management in the Southeast	Blacksburg, Va.	"	II,D-1,2
FS 1 8-16(SO)	FS-SO-1801	Wildlife habitat in Southern forests	Nacogdoches, Texas	"	II,D-1,3-a
		P.L. 480 Projects			
	E21-FS-30	The quantity,quality,and seasonal variation of food resources available to red deer in various environmental conditions of forest management	Warsaw, Poland	"	II,D-3-b

WORK AND LINE PROJECTS, FOREST PROTECTION RESEARCH DIVISION
FOREST SERVICE, U.S.D.A.

May 1, 1966 to April 30, 1967

Work and Line Project Numbers		Work and Line Project Titles	Work Locations	Line Projects Summary Index
CPO	FS			
		FOREST FIRE		
	FS-NOR-2101	Alaskan fire control methods	College, Alaska	III A,5
	FS-PNW-2103	Forest fuels appraisal	Seattle, Washington	III A,3
	FS-PNW-2104	National fire danger rating	Seattle, Washington	---
	FS-PSW-2102	Fire control systems planning	Riverside, California	III A,5
	FS-PSW-2103	Fire chemistry	Berkeley, California	III A,1
	FS-PSW-2104	Fuel break	Riverside, California	III A,4
	FS-PSW-2105	Fire prevention	Berkeley, California	III A,4
	FS-PSW-2106	Fire control tactics	Riverside, California	III A,5
	FS-PSW-2107	Fire Behavior	Riverside, California	III A,3
	FS-PSW-2108	Fire meteorology	Riverside, California	III A,2
	FS-INT-2101	Lightning Research	Missoula, Montana	III A,2
	FS-INT-2102	Fire management	Missoula, Montana	III A,4,5
	FS-INT-2103	Fire physics	Missoula, Montana	III A,1
	FS-INT-2104	Fuel science	Missoula, Montana	III A,3
	FS-INT-2105	Project fire scan	Missoula, Montana	---
	FS-INT-2106	Forest fire science	Missoula, Montana	---
	FS-RM-2102	Fire use	Flagstaff, Arizona	III A,4
	FS-NC-2101	Fire control methods	St. Paul, Minnesota	---
	FS-NC-2102	Fire damage appraisal	Columbia, Missouri	---
	FS-SE-2101	Prescribed fire	Macon, Georgia	III A,4
	FS-SE-2102	Fire control methods	Macon, Georgia	III A,5
	FS-SE-2103	Fire meteorology	Macon, Georgia	III A,2
	FS-SE-2106	Fuel physics	Macon, Georgia	---
	FS-SE-2106P	Pioneering research project	Macon, Georgia	III A,1
	FS-SO-2102	Fire prevention	Alexandria, Louisiana	III A,4

WORK AND LINE PROJECTS, FOREST PROTECTION RESEARCH DIVISION
FOREST SERVICE, U.S.D.A.

May 1, 1966 to April 30, 1967

Work and Line Project Numbers		Work and Line Project Titles	Work Locations	Line Projects Summary Index
CPO	FS			
		P.L. 480 PROJECTS		
E25-FS-13		Open fires and transport of fire brands	Madrid, Spain	
A10-FS-16		Pyrolysis of fuels in the presence of additives	Jerusalem, Israel	

WORK AND LINE PROJECTS, FOREST PROTECTION RESEARCH DIVISION
FOREST SERVICE, U.S.D.A.

May 1, 1966 to April 30, 1967

Work and Line Project Numbers		Work and Line Project Titles	Work Locations	Line Projects Summary Index
CPO	FS			
		FOREST INSECTS		
FS 2 2-3(PNW)	FS-PNW-2201	Biology, ecology, and control of forest insects in the Pacific Northwest	Portland, Oregon	III,B-1-a,4-a,e
FS 2 2-25(PNW)	FS-PNW-2203	Diseases of western forest insects	Corvallis, Oregon	III,B-1-c
	FS-PNW-2204	Nutrition, behavior, and population dynamics of western forest insects	Portland, Oregon	III,B-1-a,3,4-b,f,6
	FS-PNW-2206	Forest insects, coastal Alaska	Juneau, Alaska	III,B-4-b
	FS-PNW-2207	Forest insects of interior Alaska	Fairbanks, Alaska	III,B-1-a
FS 2 2-8(PSW)	FS-PSW-2201	Biology, ecology, and control of forest insects in California and Hawaii	Berkeley, California	III,B,2,3,4-b,c,6
FS 2 2-10(PSW)	FS-PSW-2203	Evaluation of chemical insecticides for control of forest insects	Berkeley, California	III,B-2,6
	FS-PSW-2204	Remote sensing and survey of the forest environment	Berkeley, California	III,B-6
FS 2 2-11(RM)	FS-RM-2201	Biology, ecology, and control of forest insects in the central Rocky Mountains	Ft. Collins, Colorado	III,B-1-b,4-a,b
FS 2 2-12(RM)	FS-RM-2202	Biology, ecology, and control of forest insects in the Southwest	Albuquerque, New Mexico	III,B-1-a,c,2,4-a,b
FS 2 2-13(INT)	FS-INT-2201	Insect population dynamics	Ogden, Utah	III,B-4-a,b
FS 2 2-14(INT)	FS-INT-2202	Biology of bark beetles	Missoula, Montana	III, B-4-a
FS 2 2-15(INT)	FS-INT-2203	Biology of defoliators and regeneration insects	Moscow, Idaho	III,B-1-a,4-b
FS 2 2-16(LS)	FS-NC-2201	Seed and cone, aspen, and shelter-belt insects	St. Paul, Minnesota	III,B-3,4-f,6

WORK AND LINE PROJECTS, FOREST PROTECTION RESEARCH DIVISION
FOREST SERVICE, U.S.D.A.

May 1, 1966 to April 30, 1967

Work and Line Project Numbers		Work and Line Project Titles	Work Locations	Line Projects Summary Index
CPO	FS			
		FOREST INSECTS		
FS 2 2-17(LS)	FS-NC-2202	Defoliators	St. Paul, Minnesota	III,B-2
FS 2 2-18(LS)	FS-NC-2203	Plantation insects	East Lansing, Michigan	III,B-2,3,4-c
FS 2 2-22(NE)	FS-NE-2201	Insect biology	New Haven, Connecticut	III,4-c
FS 2 2-23(NE)	FS-NE-2202	Biotic control	New Haven, Connecticut	III,B-1-c
FS 2 2-51(NE)	FS-NE-2204	Biology, ecology and silvicultural control of forest insects in the Northeastern States	Delaware, Ohio	III,B-4-c,e
FS 2 2-49(NE)	FS-NE-2205	Biology and control of shade tree pests in the Northeastern States	Delaware, Ohio	III,B-1-a,c,6
FS 2 2-53(NE)	FS-NE-2206	Biological control; insect vectors of plant diseases	Delaware, Ohio	III,B-4-a,6
FS 2 2-50(NE)	FS-NE-2207	Insect impact	New Haven, Connecticut	---
FS 2 2-25(SE)	FS-SE-2201	Bark beetles, defoliators, and sucking insects	Asheville, N. Carolina	III,B-1-a
FS 2 2-26(SE)	FS-SE-2202	Insect physiology	Durham, N. Carolina	III,B-1-a,5
FS 2 2-27(SE)	FS-SE-2203	Insects of slash pine seed, plantations, and naval stores	Olustee, Florida	III,B-2,3,4-f,6
	FS-SE-2205	Biological control	Durham, N. Carolina	III,B-1-c
	FS-SE-2206	Toxicology	Durham, N. Carolina	---
FS 2 2-31(SO)	FS-SO-2201	Wood products insects	Gulfport, Mississippi	III,B-4-d
FS 2 2-32(SO)	FS-SO-2202	Hardwood insects	Stoneville, Mississippi	III,B-2,3,4-c,6
FS 2 2-30(SO)	FS-SO-2203	Pine insects	Alexandria, Louisiana	III,B-1-c,2,4-a,5

WORK AND LINE PROJECTS, FOREST PROTECTION RESEARCH DIVISION
FOREST SERVICE, U.S.D.A.

May 1, 1966 to April 30, 1967

Work and Line Project Numbers		Work and Line Project Titles	Work Locations	Line Projects Summary Index
CPO	FS			
		P.L. 480 PROJECTS - FOREST INSECTS:		
A6-FS-4		Biological study of the more important insect pests attacking Pinus introduced from USA	Taiwan, China	
A7-FS-6		Accelerated laboratory investigations on natural resistance of woods to termites	Dehra Dun, India	
A7-FS-8		Survey of parasites for gypsy moth	Bangalore, India	
A7-FS-25		Survey for natural enemies of Hypsipyla spp. in India	Bangalore, India	
A7-FS-47		Studies on the population dynamics of the predators of Adelges spp. on silver fir and spruce in the Himalayas	Bangalore, India	B-1-a
A17-FS-6		Studies on the natural enemies of insect pests of West Pakistan forests	Rawalpindi, Pakistan	
A17-FS-9		Biology and ecology of important predators of spruce and fir aphids in Pakistan	Rawalpindi, Pakistan	III,B-1-a
E8-FS-63		Discovery and study of chemical substances in the bark of Pinus silvestris which are attractive to the bark beetle, Blastophagus piniperda L.	Helsinki, Finland	

WORK AND LINE PROJECTS, FOREST PROTECTION RESEARCH DIVISION
FOREST SERVICE, U.S.D.A.

May 1, 1966 to April 30, 1967

Work and Line Project Numbers		Work and Line Project Titles	Work Locations	Line Projects Summary Index
CPO	FS			
E21-FS-6		Investigations into the activity of the parasite, Trichogramma embryophagum (Hart) introduced into the forest environment with special attention to its capacity for spreading	Poznan, Poland	
E21-FS-38		Studies on the ecology and biology of the more important parasites of Rhyacionia buoliana Schiff. in Poland	Warsaw, Poland	
E21-FS-41		Studies in the development of improved strains of parasites of forest insects	Poznan, Poland	
E25-FS-3		Pests of poplars and preventive and curative methods of control	Madrid, Spain	III,B-2
E25-FS-10		The study of parasites, predators and diseases of the gypsy moth and the possibility of their application in the biological control	Madrid, Spain	
E25-FS-26		Microbial control of gypsy moth	Madrid, Spain	
E30-FS-2		Study of the polyhedral virus disease of the gypsy moth	Zemun, Yugoslavia	
E30-FS-9		Biological control of gypsy moth and pine sawfly	Belgrad, Yugoslavia	

WORK AND LINE PROJECTS, FOREST PROTECTION RESEARCH DIVISION
FOREST SERVICE, U.S.D.A.

May 1, 1966 to April 30, 1967

Work and Line Project Numbers		Work and Line Project Titles	Work Locations	Line Projects Summary Index
CPO	FS			
S3-FS-7		Disease and insect susceptibility and species adaptability of some North American pine species planted in Sao Paulo	Sao Paulo, Brazil	III,B-4-f
S5-FS-1		Disease and insect susceptibility and species adaptability of some North American forest tree species planted in Colombia	Medellin, Colombia	III,B-4-f
S9-FS-1		Disease and insect susceptibility and species adaptability of North American conifers planted in Uruguay	Montevideo, Uruguay	III,B-4-f
FS 2 2-38(WO)(Gr)	FS-WO-2206(Gr)	Inducing sexual sterility in the European pine shoot moth	Pullman, Washington	III, B-3
FS 2 2-39(WO)(Gr)	FS-WO-2207(Gr)	Nutritional and developmental requirements of the European pine shoot moth	Pullman, Washington	---
FS 2 2-40 (WO)(Gr)	FS-WO-2208(Gr)	Population dynamics of the jack pine budworm	Ann Arbor, Michigan	---
FS 2 2-41(WO)(Gr)	FS-WO-2209(Gr)	Factors influencing the attraction, movement, and concentration of southern bark beetles	Durham, North Carolina	---

WORK AND LINE PROJECTS, FOREST PROTECTION RESEARCH DIVISION
FOREST SERVICE, U.S.D.A.

May 1, 1966 to April 30, 1967

Work and Line Project Numbers		Work and Line Project Titles	Work Locations	Line Projects Summary Index
CPO	FS			
FS 2 2-42(WO)(Gr)	FS-WO-2210(Gr)	Chemical investigation of host plant selection by the elm bark beetle	Columbus, Ohio	---
FS 2 2-43(WO)(Gr)	FS-WO-2211(Gr)	Investigations of the microflora of healthy and diseased gypsy moth	Storrs, Connecticut	---
FS 2 2-44(WO)(Gr)	FS-WO-2212(Gr)	Taxonomy of gamasid mites predatory on or associated with bark beetles attacking southern pines	Raleigh, N. Carolina	III,B-4-a
FS 2 2-45(WO)(Gr)	FS-WO-2213(Gr)	The biology and taxonomy of root aphids on conifers	Raleigh, N. Carolina	---
FS 2 2-46(WO)(Gr)	FS-WO-2214(Gr)	Basic studies on the nature and significance of diet and reproduction in Ips species bark beetles	Gainesville, Florida	---
FS 2 2-47(WO)(Gr)	FS-WO-2215(Gr)	Sex attraction and mating biology in insects, particularly sawflies	Madison, Wisconsin	III,B-3
FS 2 2-48(WO)(Gr)	FS-WO-2216(Gr)	The physical and chemical components of host plant resistance to the European pine shoot moth	East Lansing, Michigan	---
FS-2 2-49(WO)(Gr)	FS-WO-2217(Gr)	Biological activity and fate of insecticides	Berkeley, California	---
FS 2 2-50(WO)(Gr)	FS-WO-2218(Gr)	Bark beetle-lightning strike relationships	Natchitoches, Louisiana	---
FS 2 2-51(WO)(Gr)	FS-WO-2219(Gr)	Forest tent catapillar virus	St. Paul, Minnesota	---
FS 2 2-52(WO)(Gr)	FS-WO-2220(Gr)	Role of attractants in forest insects	Berkeley, California	---
FS 2 2-53(WO)(Gr)	FS-WO-2221(Gr)	Chemistry of forest insect attractants	Menlo Park, California	---

WORK AND LINE PROJECTS, FOREST PROTECTION RESEARCH DIVISION
FOREST SERVICE, U.S.D.A.

May 1, 1966 to April 30, 1967

Work and Line Project Number		Work and Line Project Titles	Work Locations	Line Projects Summary Index
CPO	FS			
		FOREST DISEASE		
FS 2 3-1 (PNW) (R)	FS-PNW-2301 (R) Supersedes 2301 and 2304	Diseases reducing forest production	Portland, Oregon	III, C, 2-b, 3-b, 3-e 3-g, 4-a, 6-a,
FS 2 3-2 (PNW) (R)	FS-PNW-2302 (R) Supersedes 2302 and 2303	Root diseases and soil microbiology	Corvallis, Oregon	III, C, 1-b, 2-b, 2-d, 2-e
FS 2 3-5 (PSW) (R)	FS-PSW-2301 (R) Supersedes 2301 and 2302	Diseases - California and Hawaii	Berkeley, California	III, C, 1-a, 1-b, 2-a 3-a, 3-b, 3-e, 3-g
FS 2 3-7 (INT)	FS-INT-2301	Native rusts of western conifers	Logan, Utah	III, C, 3-a
FS 2 3-8 (INT)	FS-INT-2302	Breeding Western white pine resistant to blister rust	Moscow, Idaho	III, C, 3-b
FS 2 3-9 (INT)	FS-INT-2303	Diseases of western white pine and antibiotic action	Moscow, Idaho	III, C, 3-b, 3-c, 4-a
FS 2 3-10 (RM) (R)	FS-RM-2301 (R) Supersedes 2301 in part	Diseases of trees and shrubs in the Central Rocky Mountains	Fort Collins, Colorado	III, C, 3-d, 3-e, 3-f, 3-g, 4-e, 4-a
FS 2 3-11 (RM)	FS-RM-2302	Diseases of Southwest ponderosa pine and associated species	Albuquerque, New Mexico	III, C, 2-f, 3-e, 3-g, 7
FS 2 3-12 (NC)	FS-NC-2301	Diseases of northern conifers and shelterbelts	St. Paul, Minnesota	III, C, 3-d
FS 2 3-13 (NC)	FS-NC-2302	Diseases of aspen	St. Paul, Minnesota	III, C, 3-d, 3-g
FS 2 3-14 (NC)	FS-NC-2303	Diseases of northern hardwoods	Marquette, Michigan	III, C, 2-e, 4-e, 6-b, 6-c
FS 2 3-34 (NE)	FS-NE-2303	Vascular and virus diseases	Delaware, Ohio	III, C, 5-a
FS 2 3-35 (NE)	FS-NE-2304	Cankers, heartrots, and physiogenic diseases	Delaware, Ohio	III, C, 2-c, 3-d, 3-g, 6-d, 7
FS 2 3-17 (NE)	FS-NE-2301	Mid-Atlantic tree diseases	Upper Darby, Penn	III, C

WORK AND LINE PROJECTS, FOREST PROTECTION RESEARCH DIVISION
FOREST SERVICE, U.S.D.A.

May 1, 1966 to April 30, 1967

Work and Line Project Number		Work and Line Project Titles	Work Locations	Work Projects Summary Index
CPO	FS			
FS 2 3-18 (NE)	FS-NE-2302	New England and New York tree diseases	West Haven, Connecticut	III,C,3-d,3-g,4-c, 6-b, 7
FS 2 3-20 (SE) (R)	FS-SE-2302 (R)	Annosus root rot	Durham, N. Carolina	III,C,2-a,2-c
FS 2 3-21 (SE) (R)	FS-SE-2303 (R) Supercedes 2301 and 2303	Rusts, nursery and hardwood diseases	Asheville, North Carolina	III,C,3-a,3-c
FS 2 3-22 (SE) (R)	FS-SE-2304 (R)	Soil-borne organisms	Athens, Georgia	III,C,1-a,1-b,2-c 2-f
FS 2 3-23 (SE)	FS-SE-2305	Air pollution	Asheville, North Carolina	III,C,4-c
FS 2 3-24 (SO)	FS-SO-2301	Wood decay	New Orleans, Louisiana	III,C,6-b
FS 2 3-25 (SO)	FS-SO-2303	Southern pine diseases	Gulfport, Mississippi	III,C,3-c,
FS 2 3-26 (SO)	FS-SO-2302	Bottomland hardwood diseases	Stoneville, Mississippi	III,C,2-e
FS 2 3-27 (WO)	FS-WO-2301	Biology, physiology, genetics, and cultural characteristics of forest fungi	Laurel, Maryland	III,C,6-e
FS 2 3-28 (RM)	FS-RM-2303	Diseases of field windbreaks and nurseries in the Great Plains	Lincoln, Nebraska	III,C,4-b,5-b
FS 2 3-29 (WO)(Gr)	FS-WO-2303 (Gr)	Aerobiology of piedmont forest fungi	Durham, N. Carolina	III, C
FS 2 3-30 (WO)(Gr)	FS-WO-2302 (Gr)	Biochemistry of wood deterioration	Raleigh, N. Carolina	III,C,6-d
FS 2 3-31 (WO)(Gr)	FS-WO-2304 (Gr)	White pine blister rust resistance	Madison, Wisconsin	III,C,3-b
FS 2 3-32 (WO)(Gr)	FS-WO-2305 (Gr)	Enzymic and nutritional studies of *Cronartium fusiforme*	Jackson, Mississippi	III,C,3-c
FS 2 3-33 (WO)(Gr)	FS-WO-2306 (Gr)	Biology and biochemistry of root exudates	Ossining, New York	III,C,2-a

WORK PROJECTS, FOREST PROTECTION RESEARCH DIVISION
FOREST SERVICE, U.S.D.A.

May 1, 1966 to April 30, 1967

Work and Line Project Numbers		Work and Line Project Titles	Work Locations	Line Projects Summary Index
CPO	FS			
FS 2 3-36 (WO) (Gr)	FS-WO-2307 (Gr)	Spore germination and host penetration by heart-roting fungi	University Park, Pennsylvania	III, g
		P.L. 480 PROJECTS		
A6-FS-3		Important epidemic diseases of forest trees in Taiwan	Taipei, Taiwan	III, C, 1-a 3-d
A7-FS-5		Accelerated laboratory investigations of durability of wood	Dehra Dun, India	III, C, 6-d
A7-FS-28		Biochemical studies of the Loranthaceae	Lucknow, India	III, C, 3-f
E15-FS-5		Biology and epidemiology of pine twist rust	Florence, Italy	III, C, 4-d
E21-FS-21		Forest tree seed disease organisms	Warsaw, Poland	III, C, 1-a
E21-FS-35		Saprophytic and semi-parasitic fungi as an environmental factor in the forest influencing the destructive activity of Armillaria mella and Fomes annosus	Poznan, Poland	III C, 2-a
E21-FS-37		Occurrence and impact of diseases and insects of U.S. trees planted in certain regions of Poland	Warsaw, Poland	III, C, 1-c
E30-FS-5		Susceptibility to diseases and insects of selected North American forest tree species planted in Yugoslavia	Jastrebarsko, Yugoslavia	III, C, 1-c

WORK AND LINE PROJECTS, FOREST PROTECTION RESEARCH DIVISION
FOREST SERVICE, U.S.D.A.

May 1, 1966 to April 30, 1967

Work and Line Project Number CPO	FS	Work and Line Project Titles	Work Location	Work Projects Summary Index
S3-FS-7		Disease susceptibility of some North American tree species in Sao Paulo	Sao Paulo, Brazil	III, C, 1-c
S5-FS-1		Disease susceptibility of some North American tree species in Colombia	Medellin, Colombia	III, C, 1-c
S9-FS-1		Disease susceptibility of some North American tree species in Uruguay	Montevideo, Uruguay	III, C, 1-c

WORK AND LINE PROJECTS, FOREST PRODUCTS AND ENGINEERING RESEARCH DIVISION
FOREST SERVICE, U.S.D.A.

May 1, 1966 to April 30, 1967

Work and Line Project Number		Work and Line Project Titles	Work Locations	Line Projects Summary Index
CPO	FS			
		WOOD QUALITY RESEARCH		
FS 3 1-1 (FPL)	FS-FPL-3101	Wood structure and identification	Madison, Wis.	
FS 3 1-2 (FPL)	FS-FPL-3102	Fine wood structure	Madison, Wis.	IV, A, 1-b, 1-c
FS 3 1-3 (FPL)	FS-FPL-3103	Wood structure-wood property relations	Madison, Wis.	
FS 3 1-4 (FPL)	FS-FPL-3104	Environmental, growth, and silvicultural effects	Madison, Wis.	
FS 3 1-5 (FPL)	FS-FPL-3105	Wood quality evaluation and genetic effects	Madison, Wis.	
FS 3 1-6 (FPL)	FS-FPL-3106	Log and tree grade development	Madison, Wis.	
FS 3 1-7 (FPL)	FS-FPL-3107	Lumber quality yield development	Madison, Wis.	IV, A, 1-a
FS 3 1-8 (FPL)	FS-FPL-3108	Sawmill improvement	Madison, Wis.	IV, A, 2-d
FS 3 1-9 (PNW)	FS-PNW-3101	Grade and quality of Western timber	Portland, Ore.	IV, A, 1-a
FS 3 1-10 (PSW)	FS-PSW-3101	Western pine (and associated species) log and tree grades	Berkeley, Calif.	
FS 3 1-11 (NE)	FS-NE-3102	Hardwood log and tree grades	Columbus, Ohio	
FS 3 1-12 (NE)	FS-NE-3101	Grade and quality of Eastern softwood timber	Upper Darby, Pa.	
FS 3 1-13 (SE) (R)	FS-SE-3101 (Rev.)	Grade and quality of Southern timber	Athens, Ga.	I, C, 1
FS 3 1-14 (WO) (GR)	FS-WO-3101 (GR)	Variation in the cell wall density of wood	New Haven, Conn.	
		SOLID WOOD PRODUCTS RESEARCH		
FS 3 2-1 (FPL)	FS-FPL-3201	Machining and veneer cutting	Madison, Wis.	IV, A, 2-c
FS 3 2-2 (FPL)	FS-FPL-3202	Product and process development	Madison, Wis.	IV, A, 2-b
FS 3 2-3 (FPL)	FS-FPL-3203	Wood drying	Madison, Wis.	IV, A, 2-a
FS 3 2-4 (FPL)	FS-FPL-3204	Glues and gluing processes	Madison, Wis.	
FS 3 2-5 (FPL)	FS-FPL-3205	Glued wood products	Madison, Wis.	
FS 3 2-6 (FPL)	FS-FPL-3206	Wood finishing	Madison, Wis.	IV, A, 2-e
FS 3 2-7 (FPL)	FS-FPL-3207	Fire performance of wood	Madison, Wis.	IV, A, 5-a
FS 3 2-8 (FPL)	FS-FPL-3208	Environmental effects	Madison, Wis.	IV, A, 5-b, 5-c
FS 3 2-9 (FPL)	FS-FPL-3209	Preservative development and treating processes	Madison, Wis.	
FS 3 2-10 (FPL)	FS-FPL-3210	Wood fungus and insects effects and control	Madison, Wis.	III, C, 6-b, 6-c, 6-d, 6-e, 7
FS 3 2-11 (WO) (GR)	FS-WO-3201 (GR)[1/]	Swelling of wood on its permeability to organic liquids	St. Paul, Minn.	
		WOOD FIBER PRODUCTS RESEARCH		
FS 3 3-1 (FPL)	FS-FPL-3301	Pulping process investigations	Madison, Wis.	IV, A, 3-b
FS 3 3-2 (FPL)	FS-FPL-3302	Pulp properties	Madison, Wis.	

[1/] Initiated during reporting period

WORK AND LINE PROJECTS, FOREST PRODUCTS AND ENGINEERING RESEARCH DIVISION
FOREST SERVICE, U.S.D.A.

May 1, 1966 to April 30, 1967

Work and Line Project Number		Work and Line Project Titles	Work Locations	Line Projects Summary Index
CPO	FS			
FS 3 3-3 (FPL)	FS-FPL-3303	Fiber processing	Madison, Wis.	
FS 3 3-4 (FPL) (R)	FS-FPL-3304 (Rev.) supersedes 3304 and 3305 in part	Papermaking and converting processes	Madison, Wis.	IV, A, 3-a
FS 3 3-6 (FPL)	FS-FPL-3306 supersedes 3305 in part	Fundamental properties of paper	Madison, Wis.	
		WOOD CHEMISTRY RESEARCH		
FS 3 4-1 (FPL)	FS-FPL-3401	Wood carbohydrates and conversion products	Madison, Wis.	IV, A, 4-a
FS 3 4-2 (FPL)	FS-FPL-3402	Lignin structure and utilization	Madison, Wis.	IV, A, 4-c
FS 3 4-3 (FPL)	FS-FPL-3403	Chemistry of wood and bark extractives	Madison, Wis.	IV, A, 4-b
FS 3 4-4 (FPL)	FS-FPL-3404	Biochemistry of wood constituents	Madison, Wis.	
FS 3 4-5 (FPL)	FS-FPL-3405	Surface and polymer chemistry of wood	Madison, Wis.	IV, A, 4-e
FS 3 4-6 (FPL)	FS-FPL-3406	Process development	Madison, Wis.	
FS 3 4-7 (FPL)	FS-FPL-3407	Analytical development, instrumentation, and service	Madison, Wis.	
FS 3 4-8 (WO) (GR)	FS-WO-3401 (GR)[1/]	The chemistry and ultra-structure of reaction wood	Syracuse, N.Y.	IV, A, 4-d
FS 3 4-9 (WO) (GR)	FS-WO-3402 (GR)[1/]	Free radical studies of lignin related model compounds	Tucson, Ariz.	
FS-P-3	FS-P-3	Pioneering research in lignin chemistry	Madison, Wis.	IV, A, 4-c
		WOOD ENGINEERING RESEARCH		
FS 3 5-1 (FPL)	FS-FPL-3501	Fundamental wood properties	Madison, Wis.	IV, A, 6-f
FS 3 5-2 (FPL)	FS-FPL-3502	Properties of wood-base and related materials	Madison, Wis.	
FS 3 5-3 (FPL)	FS-FPL-3503	Analytical mechanics	Madison, Wis.	
FS 3 5-4 (FPL)	FS-FPL-3504	Research equipment and method development	Madison, Wis.	
FS 3 5-5 (FPL)	FS-FPL-3505	Design criteria	Madison, Wis.	IV, A, 6-c
FS 3 5-6 (FPL)	FS-FPL-3506	Structural utilization	Madison, Wis.	IV, A, 6-a, 6-b
FS 3 5-7 (FPL)	FS-FPL-3507	Packaging	Madison, Wis.	IV, A, 6-e

1/ Initiated during reporting period

WORK AND LINE PROJECTS, FOREST PRODUCTS AND ENGINEERING RESEARCH DIVISION
FOREST SERVICE, U.S.D.A.

May 1, 1966 to April 30, 1967

Work and Line Project Number		Work and Line Project Titles	Work Locations	Line Projects Summary Index
CPO	FS			
		REGIONAL UTILIZATION RESEARCH		
FS 3 6-1 (SE) (R)	FS-SE-3601 (Rev.) supersedes 3601, 3602, and 3603	Housing research, SE	Athens, Ga.	IV, A, 6-d
FS 3 6-4 (CS)	FS-CS-3601 2/	Utilization improvement, CS	Columbus, Ohio	
FS 3 6-5 (CS)	FS-CS-3602 2/	Using Central States timber, CS	Carbondale, Ill.	
FS 3 6-6 (NE)	FS-NE-3601 2/	Utilization improvement, CS	Upper Darby, Pa.	
FS 3 6-7 (ITF)	FS-ITF-3601 2/	Timber utilization, Tropics, ITF	Rio Piedreas, P.R.	
FS 3 6-8 (LS)	FS-LS-3601 2/	Timber characterization and processing, LS	Duluth, Minn.	
FS 3 6-9 (LS)	FS-LS-3602 2/	Utilization improvement, LS	St. Paul, Minn.	
FS 3 6-11 (PNW)	FS-PNW-3601 2/	Utilization improvement, PNW	Seattle, Wash.	
FS 3 6-12 (PNW)	FS-PNW-3602 1/	Wood construction concepts, PNW	Seattle, Wash.	
FS 3 6-13 (PSW)	FS-PSW-3601	Utilization improvement, PSW	Berkeley, Calif.	
FS 3 6-15 (INT)	FS-INT-3601	Utilization improvement, INT	Missoula, Mont.	IV, A, 2-a
FS 3 6-17 (RM)	FS-RM-3601	Utilization improvement, RM	Fort Collins, Colo.	
FS 3 6-19 (SO) (R)	FS-SO-3601 (Rev.)	Processing southern woods, SO	Alexandria, La.	IV, A, 2-g
FS 3 6-20 (NC)	FS-NC-3604 1/	Improve utilization of timber for primary forest products, NC	Duluth, Minn.	
FS 3 6-21 (NC)	FS-NC-3603 1/ supersedes CS-3602	Hardwood processing, NC	Carbondale, Ill.	
FS 3 6-22 (NE)	FS-NE-3602 1/	Hardwood product improvement, NE	Princeton, W.Va.	IV, A, 2-f
		FOREST ENGINEERING RESEARCH		
FS 3 7-1 (INT)	FS-INT-3701	Engineering systems for steep mountain forestry	Bozeman, Mont.	IV, B, 1
FS 3 7-2 (NC)	FS-NC-3701	Engineering systems for northern hardwoods	Houghton, Mich.	IV, B, 2
FS 3 7-3 (SO)	FS-SO-3701	Engineering systems for intensive forest management	Auburn, Ala.	
FS 3 7-4 (PNW)	FS-PNW-3701	Engineering systems for heavy timber stands in the Pacific Northwest and Alaska	Seattle, Wash.	IV, B, 3
FS 3 7-5 (NE)	FS-NE-3701	Engineering systems for Appalachian type forestry	Morgantown, W.Va.	

1/ Initiated during reporting period
2/ Terminated during reporting period

WORK AND LINE PROJECTS, FOREST PRODUCTS AND ENGINEERING RESEARCH DIVISION
FOREST SERVICE, U.S.D.A.

May 1, 1966 to April 30, 1967

Work and Line Project Number		Work and Line Project Titles	Work Locations	Line Project Summary Index
CPO	FS			
		P.L. 480 PROJECTS		
S8-FS-3 1/		Collection of wood samples, etc., from forest trees of Peru	Lima, Peru	
A17-FS-2		Preservative absorption and penetration in tropical timber	Sholashahar, Chittagong, E. Pakistan	
A17-FS-7		Collection and identification of trees and wood samples of E. Pakistan	Sholashahar, Chittagong, E. Pakistan	
A7-FS-3		Working qualities of Indian timbers	Dehra Dun, India	
A7-FS-4		Density and fiber as indicators of wood quality	Dehra Dun, India	IV, A, 7
A7-FS-16		Hardwood seasoning	Dehra Dun, India	IV, A, 7
A7-FS-27		Phenolic constituents of woods and barks	Dehra Dun, India	
A7-FS-42		Wood phenolics	Poona, India	

1/ Initiated during reporting period

WORK AND LINE PROJECTS, FOREST ECONOMICS AND MARKETING RESEARCH DIVISION
FOREST SERVICE, U.S.D.A.

May 1, 1966 to April 30, 1967

Work and Line Project Number		Work and Line Project Titles	Work Locations	Line Projects Summary Index
CPO	FS			
		FOREST SURVEY		V
FS 4 1-1 (NOR)	FS-NOR-4101	Forest Survey--NOR	Juneau, Alaska	V, A-1,7
FS 4 1-2 (PNW)(R)	FS-PNW-4101	Forest Survey--PNW	Portland, Oregon	V, A-1
FS 4 1-3 (PNW)(R)	FS-PNW-4102 (Rev.)	Survey Techniques--PNW	Portland, Oregon	V, A-3
FS 4 1-5 (INT)	FS-INT-4101	Forest Survey--INT	Ogden, Utah	V, A-1,4
FS 4 1-6 (NC)	FS-NC-4101	Forest Survey--NC	St. Paul, Minnesota	V, A-1,2
FS 4 1-7 (NE)(R)	FS-NE-4101 (Rev.)	Forest Survey--NE	Upper Darby, Pennsylvania	V, A-1,5
FS 4 1-8 (SO)	FS-SO-4101	Forest Survey--SO	New Orleans, Louisiana	V, A-1
FS 4 1-9 (SE)	FS-SE-4101	Forest Survey--SE	Asheville, North Carolina	V, A-1,2
FS 4 1-10 (WO)	FS-WO-4101	Survey Techniques--WO	Washington, D. C.	V, A-6
		FOREST ECONOMICS		V
FS 4 2-1 (PNW)(R)	FS-PNW-4201 (Rev.)	Production Economics--PNW	Portland, Oregon	V, B-4,5
FS 4 2-4 (PSW)	FS-PSW-4201	Production Economics--PSW	Berkeley, California	V, B
FS 4 2-7 (INT)	FS-INT-4201	Production Economics--INT	Ogden, Utah	V, B
FS 4 2-8 (INT)	FS-INT-4202	Multiple-Use Economics--INT	Ogden, Utah	V, B
FS 4 2-9 (RM)	FS-RM-4201	Watershed Economics--RM	Flagstaff, Arizona	V, B
FS 4 2-11 (NC)	FS-NC-4201	Economics of Timber Growing in the Northern Hardwood and Conifer Types--NC	St. Paul, Minnesota	V, B-2,7
FS 4 2-14 (NE)	FS-NE-4204(CS-4202)	Timber Program Evaluations--NE	Columbus, Ohio	V, B
FS 4 2-15 (SO)(R)	FS-SO-4201 (Rev.)	Production Economics--SO	New Orleans, Louisiana	V, B
FS 4 2-18 (NE)	FS-NE-4201	Regional Production Economics--NE	Upper Darby, Pennsylvania	V, B-1
FS 4 2-19 (NE)	FS-NE-4202	Economics of Forest Management--NE	Upper Darby, Pennsylvania	V, B-3,6
FS 4 2-25 (WO)	FS-WO-4202	Forest Finance--WO	Washington, D. C.	V, B
		FOREST PRODUCTS MARKETING		V
FS 4 3-1 (PNW)	FS-PNW-4301	Marketing--PNW	Portland, Oregon	V, C-10
FS 4 3-2 (PSW)	FS-PSW-4301	Marketing--PSW	Berkeley, California	V, C
FS 4 3-3 (INT)	FS-INT-4301	Evaluation of Opportunities for Enhancing Marketing of Rocky Mountain Timber Products--INT	Ogden, Utah	V, C
FS 4 3-4 (RM)	FS-RM-4301	Forest Products Marketing--RM	Fort Collins, Colorado	V, C

WORK AND LINE PROJECTS, FOREST ECONOMICS AND MARKETING RESEARCH DIVISION
FOREST SERVICE, U.S.D.A.

May 1, 1966 to April 30, 1967

Work and Line Project Number		Work and Line Project Titles	Work Locations	Line Projects Summary Index
CPO	FS			
		FOREST PRODUCTS MARKETING		V
FS 4 3-5 (NC)	FS-NC-4301	Marketing--NC	Duluth, Minnesota	V, C-9,12
FS 4 3-6 (NE)	FS-NE-4306 1/	Marketing Practices--NE	Berea, Kentucky	V, C-6,13
FS 4 3-7 (NC)	FS-NC-4302	Market Development--NC	Carbondale, Illinois	V, C-5
FS 4 3-9 (NE)	FS-NE-4301	Improvement of Timber Products Marketing Practices in the Northeast--NE	Upper Darby, Pennsylvania	V, C
FS 4 3-10 (NE)	FS-NE-4302	Marketing Development--NE	Princeton, West Virginia	V, C-3,4,6,11
FS 4 3-11 (SE)	FS-SE-4301	Improvement of Marketing of Wood Used in Construction--SE	Asheville, North Carolina	V, C-2,7,8,14
FS 4 3-12 (WO)(GR)	FS-WO-4302	Importance of Noise and Its Potential Effect on Wood Use in Garden Apartments--WO	Ames, Iowa	V, C
FS 4 3-13 (WO)	FS-WO-4301	Requirements--WO	Washington, D. C.	V, C-1

1/ Formerly FS-CS-4301.

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